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THE PHYSICAL GEOGRAPHY
OF NEW YORK STATE

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THE
PHYSICAL GEOGRAPHY OF
NEW YORK STATE

BY

RALPH S. TARR

Professor of Dynamic Geology and Physical Geography at Cornell University. Author of
"Elementary Physical Geography," "First Book of Physical Geography."
"Elementary Geology," etc., and co-author of the Tarr & McMurry Geographies.

(WITH A CHAPTER ON CLIMATE
BY E. T. TURNER)

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PREFACE

At the request of the American Geographical Society in 1896 a series of articles on the Physical Geography of New York State was undertaken and the first number appeared in the Bulletin of the American Geographical Society, Vol. XXVIII, 1896, page 99. When these articles were begun it was my intention to cover the subject in two or three numbers; but after getting well into the task it became evident that to cover the field with any fulness would require many more chapters than were originally planned and, therefore, the series lengthened out to twelve numbers and was not finished until 1900.

Since the preparation of the manuscript called for the careful consideration of the work of various investigators, there necessarily developed in connection with the work a rather full bibliography of the physical geography of New York; and, since the work of these investigators was made use of to such a marked extent, references were made to the numerous articles. The series therefore contained a rather full bibliography.

As there is at present no complete account of the physiographic features of New York State, and no published bibliography of the literature on this subject, it has seemed to me well to group these articles together in a single publication, especially since the Bulletin of the American Geographical Society is inaccessible to most geography teachers. I have been led to believe that there is some call for such a treatment on the part of the more progressive geography teachers in the State, and it is for this class of readers, and for similar teachers in other sections of the country, that the book is primarily intended. While naturally the greater part of the material in the book is based upon the work of others, I have in many instances drawn upon my own observations in various parts of the State.

In the main the book is a reprint of the articles as published in the Bulletin of the American Geographical Society, but there has necessarily been a certain amount of revision, and many of the more important papers on the subject which have appeared since the original publication of the articles have been made use of, so that in the main the bibliography has been brought down to date. The chapter on Climate (Chapter XI), was written for the Bulletin as a part of the series, and Mr. Turner has kindly given permission to reprint it in this volume. Acknowledgment is due the American Geographical Society for permission to republish these articles and for the loan of most of the cuts. A few cuts have been loaned by the Nature Study Bureau, Cornell University. The photographs used have been obtained from various sources; where they were not taken by the author acknowledgment to the photographer has been made in the legend. I am further indebted to Mr. Lawrence Martin for assistance in proof-reading and in making the index and bibliography.

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CHAPTER I

GENERAL PHYSIOGRAPHIC FEATURES

PHYSIOGRAPHIC PROVINCES

GENERAL FEATURES.—On its northern side the State of New York has natural boundaries for the greater part of its distance; but nearly everywhere else the boundaries are purely artificial. In consequence of this, most of the physiographic provinces of the State are merely portions of larger areas which extend into it from the neighboring States. Viewed broadly, and excluding the New England border, there are two highland areas and one branching area of lowlands (Figs. 1, 2 and 3). If the sea should rise only a few hundred feet, it would extend up the Hudson valley, across the divide into the basin of Lake Champlain, and thence into the St. Lawrence and Lake Ontario. At the same time, it would reach up the Mohawk, pass across the divide at Rome and join with the waters of the Ontario basin. Then the Adirondacks would become an island, separated from the Green Mountains of Vermont by a narrow channel, from the Highlands of Canada by a broad strait, and from the Catskills and the plateau of central and southern New York by a strait of intermediate width. As a result of this change the Long Island province would be entirely submerged in the sea.

LONG ISLAND PROVINCE (Fig. 4).—Examining the topography of the State in a little more detail, we find these

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[1] In later pages references are made to special papers upon individual features. General descriptions are found in the following: Eaton, Geological and Agricultural Survey of the District adjoining the Erie Canal in the State of New York, Albany, 1824; Henry, Trans. Albany Inst., I, 1830, 87-112; Natural History of New York, Geology, Part I, Mather; Part II, Emmons; Part III, Vanuxem; Part IV, Hall, 1842-3; Emmons, Natural History of New York, Agriculture; Vols. I-IV, 1846-1851; New York State Museum, Report 47, 1894, Albany.

highland and lowland areas capable of considerable subdivision. There is, first, the sandy lowland of Long Island, barely separated from the mainland, yet quite distinct from it in its general features of outline and in its rock structure. The highest elevation is about 380 feet, and the plains average only about 70 feet above sea level.[1] It is really a northward extension of the coastal province of New Jersey; but its surface is decidedly modified by deposits of glacial drift.[2]

GNEISSIC HIGHLAND PROVINCE (Fig. 4).—Passing to the mainland, there commences a province of complex structure, and one in which, in the main and most typical part of the province, the rocks are, for the most part, very much folded and disturbed metamorphic strata of ancient date. These rocks form an extension of the Highlands of New Jersey,[3] which reach across the southern angle of New York, extend northward, and enter Connecticut. Besides these ancient gneisses, there is some sandstone[4] and a black diabase, or trap, which forms the Palisades,[5] besides extensive layers of limestone, gneiss and schist, which extend across the region occupied by the city of New York.[6] This whole series of strata, with the exception of the sandstone and traps, is intricately folded.

Excepting at the very seashore, this province is a moderate highland, with rather rough topography and with hills rising in some places to an elevation of 1,000 or 1,200 feet above sea level. Where there is limestone or sandstone in this area, there is usually a lowland, while away from the seashore, highlands occur wherever the hard gneiss comes to the surface. This is extremely well illustrated in Rockland County, where the gneissic Ramapo Mountains are faced at their southeastern base by a lowland, a somewhat rolling plain, which, however, is bounded by another highland on its eastern margin where the trap of the Palisades (Fig. 20) rises close by the Hudson River. At many points near the eastern boundary of this highland region the Ramapo Mountains rise to a height of 1,100 or 1,200 feet above sea level, while the average elevation of the hills on the sandstone plain at its base

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[1] Amer. Journ. Sci., XIII, 1877, 235.

[2] Upham, Amer. Journ. Sci., XVIII, 1879, 81–92; 197–209; Mather, Geology of New York, Part I, 1843, 161; 248–278.

[3] Chiefly described in New Jersey Geological Survey Reports; also Pierce, Amer. Journ. Sci., II, 1820, 181–199; same, V, 1822, 26–33; Eaton, same, V, 1822, 231–235; Shepard, same, XXI, 1832, 321–334.

[4] Mather, Geology of New York, Part I, 1843, 285–294; Russell, Annals New York Acad. Sci., I, 1879, 220–254; Russell, Bull. 85, U. S. Geol. Survey, 1892.

[5] Mather, Geology of New York, Part I, 1843 278–285; 465–487; 534–541; Wurtz, Proc. New York Lyceum Nat. Hist., I, 1870, 99–105; Darton, Bulletin 67, U. S. Geol. Survey, 1890; New Jersey Reports, especially Kummel, Annual Report for 1897, 23–149.

[6] Mather, Geology of New York, Part I, 1843, 441–464; 525–534; Gale, same, 581–604; Britton, Annals New York Acad. Sci., II, 1882, 161–184; Transactions of same, VI, 1886, 12–18; also references for Taconic Province (p. 4); Kemp, Trans. New York Acad. Sci., VII, 1887, 49–64.

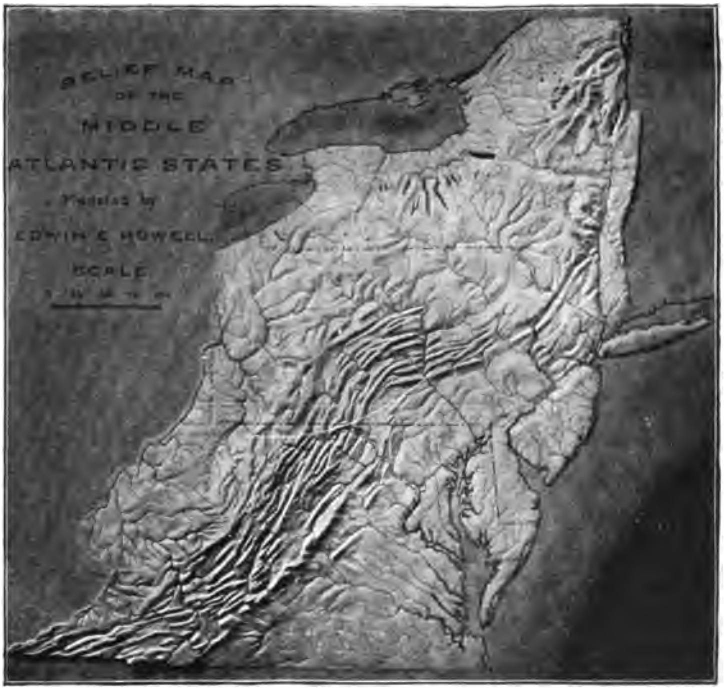

Fig. 1. Relief map of the Middle Atlantic States, to show the physiographic position of New York.

is not more than one-half this. The highlands of the Palisades in some places rise to 700 or 800 feet above the sea.

It would be possible to subdivide this province; and indeed it would be necessary to do so if we were to extend our examination of the surface into minute details. There are: (1) The low hills and highlands of the immediate coast, including all of New York County and a part of Westchester County; (2) the Palisade range of trap rock; and (3) the small angle of Triassic sandstone which extends from New Jersey into New York as a wedge-shaped area of undulating plain—a low, hilly province occupying the apex of the angle between the Palisades and the gneissic highlands. West of this is: (4) the gneissic highland proper in western Rockland, eastern Orange and a large part of Putnam counties. This fourth portion of the province forms the western member of the general highland area. The Hudson River crosses it, cutting the strata diagonally and thus trenching the highland area throughout its width. The axes of the folds in this region are almost uniformly northeast and southwest, and the folding has been extremely complex.

TACONIC PROVINCE[1] (Fig. 4).—West of the gneissic highland is a much lower area of folded rock. It extends as a broad valley northward from Pennsylvania, across New Jersey, and into Orange County, New York; then, crossing the Hudson, it extends along the state boundary into the

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[1] The Taconic area has served as the basis for an extremely prolonged controversy. The reports of the Geological Surveys of Vermont, Massachusetts and Connecticut contain facts upon this province. Besides these, reference may be made to the following: Dewey, Amer. Journ. Sci., II, 1820, 246–249; Barnes, Amer. Journ. Sci., V, 1822, 8–21; Dewey, Amer. Journ. Sci., VIII, 1824, 1–60; 240–244; Emmons, Geology of New York, Part II, 1842, 135–164; Mather, Geology of New York, Part I, 1843, 366–438; Dana, Amer. Journ. Sci., XIV, 1877, 37–48; 132–140; 202–7; 257–64; XVII, 1879, 375–388; XVIII, 1879, 61–64; XIX, 1880, 153–155 (contains a Bibliography); 191–200; 236–237; XX, 1880, 21–32; 194–220; 359–375; 450–456; XXI, 1881, 425–443; XXII, 1881, 103–119; 313–315; 327–335; Dwight, Amer. Journ. Sci., XVII, 1879, 389–92; XIX, 1880, 50–54; 451–453; XXI, 1881, 78–79; Dale, Amer. Journ. Sci., XVII, 1879, 57–59; Ford, Amer. Journ. Sci., XIX, 1880, 225–226; Dale, Thirteenth Annual Rept. U. S. Geol. Survey, 1893, 291–340; Pumpelly, Wolff and Dale, Monograph XXIII, U. S. Geol. Survey, 1894, Washington, D. C.

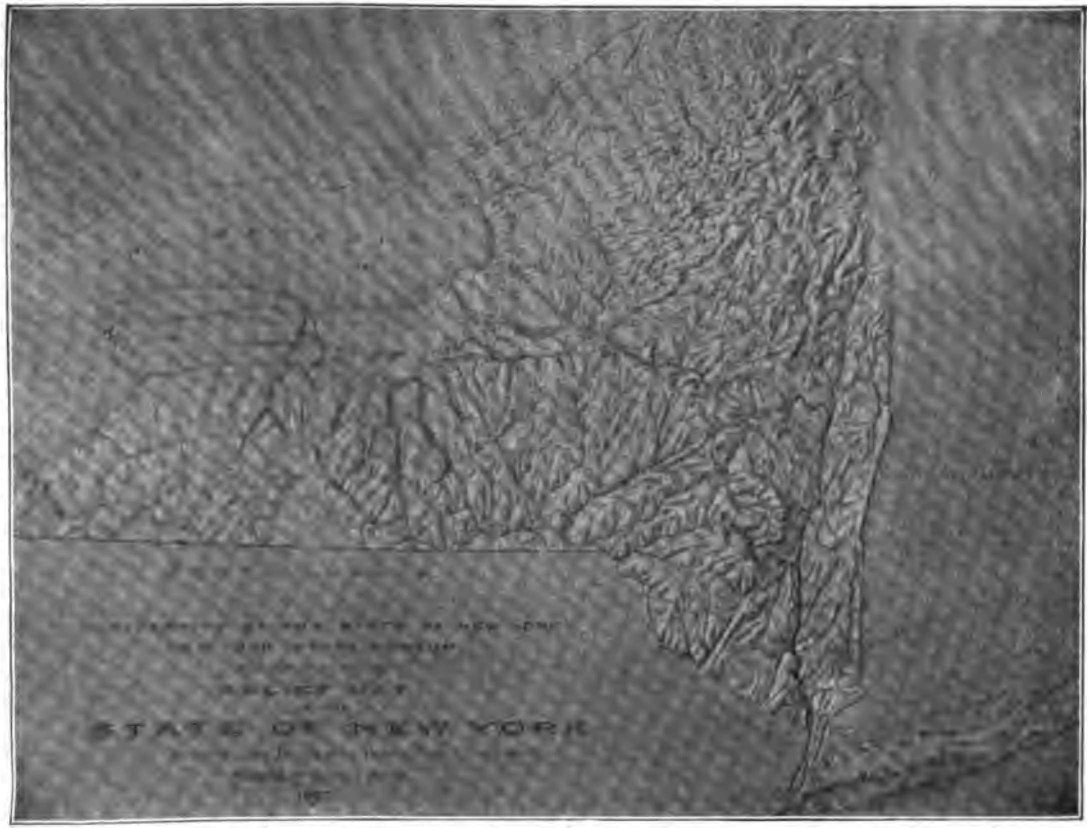

FIG. 2. Photograph of Howell's relief map of New York, modeled for the New York State Museum.

States of Connecticut, Massachusetts and Vermont. The rocks are mostly shales, slates, schists and limestones; but in the northern portion some of the strata are durable quartzite and even gneiss. While in the southern portion the topography is that of a valley, in the northern part this province becomes transformed into a region of highlands, and indeed of real mountains. This is true of the Taconic range, on the boundary between Massachusetts and Rensselaer County, which in places rises to an elevation of more than 2,800 feet above sea-level. This same system of folding crosses Vermont to Canada.

Throughout its entire extent the rocks of this province are folded, and the topography hilly (Fig. 13); but in the southern part it is a broad, gently undulating valley between two highlands, for its rocks are softer and more easily denuded than those forming its boundaries. Towards the northeast, near Massachusetts and Vermont, metamorphism has altered the strata until they are harder than the surrounding rocks; and hence they form true mountains, sloping on the one side toward the valley of the Hudson, and on the other toward the Connecticut. After passing the latitude of the boundary between Vermont and Massachusetts, this province is almost entirely within the State of Vermont; for the Lake Champlain depression marks its western boundary. From Glens Falls southward to Catskill, the Hudson may be considered as the approximate western boundary of this area; but south of Catskill the Hudson turns away from the boundary, enters the area and crosses it, then enters and extends across the gneissic highlands. While the rocks in the northern Taconic area are so metamorphosed that it is often impossible to determine their original condition, toward the south they become less and less changed; and there (as well as in a few places to the north) we are able to see that they belong to the Cambrian and Lower Silurian periods. On page 24 it is shown that the rocks of this area were all folded at one time; and hence the area may properly be separated from the complex gneissic province.[1]

CATSKILL PROVINCE[2] (Fig. 4).—The folded rocks of the Appalachians (Fig. 1) enter New York in western Orange and eastern Sullivan counties; and in that region the folds have determined a series of ridges which make that part of the State a truly mountainous section, notably in Shawangunk Mountain (Fig. 17), where a tilted conglomerate rock caps the ridge.[3]

North and west of the mountainous section the folds gradually disappear and the province changes to its typical condition of a plateau. There the rocks are Devonian sandstones, conglomerates, shales, and limestones, the first two capping the plateau. These durable sandstones and conglomerates are so carved by denudation (Fig. 23) that the plateau region, in which some of the peaks are more than 3,500 feet, and one even 4,205 feet above the sea-level, is commonly known by the name of Catskill Mountains. The western boundary of the Catskill province is not easily drawn with definiteness; but the eastern boundary is marked by a fairly continuous highland overlooking the lower region of the Taconic province, and the northern by the strongly developed Helderberg escarpment[1] (see pages 9 and 59).

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[1] Some may question the value of a separation of these eastern folded sections into two provinces; and, so far as New York is concerned, the division may not be warranted. Really the folding of the Taconic rocks involved the more ancient gneissic highlands also, and the rocks of Westchester County are mostly of Taconic age. The true Taconic province therefore divides in Putnam County, one portion passing southwards into Westchester County (see articles by Dana referred to on p. 4. See also Prosser, Trans. New York Acad. Sci. XI, 1892, 132–149). One might therefore speak of the whole eastern margin of the State, exclusive of Long Island, as the Taconic area, which extends eastward at least as far as the Connecticut. This could then be subdivided into (1) the eastern, Westchester County Taconic, (2) the Palisade range, (3) the Triassic sandstone, (4) the Archean Highlands, and (5) the main Taconic area, mountainous in the north and lowland in the south.

[2] Dwight, Amer. Journ. Sci. II, 1820, 11–29; Barton, Amer. Journ. Sci. IV, 1822, 249–251; Pierce, Amer. Journ. Sci. VI, 1823, 86–97; Vanuxem, Geology of New York, Part III, 1842, 186–194; Mather, Geology of New York, Part I, 1843, 299–316; Hall, Proc. Amer. Assoc. Adv. Sci. XXIV, 1875, Part 2, 80–84; Guyot, Amer. Journ. Sci. XIX, 1880, 429–451; Julien, Trans. New York Acad. Sci. I, 1881, 24–27; Newberry, same, 28–31; Darton, Report 47, New York State Museum, 1894, 485–566.

[3] See Mather, Geology of New York, 1st District, 1843, 355–7; Darton, Nat. Geog. Mag., VI, 1894, 23–34; New York State Museum Report 47, 1894, 485–566.

This province might also be subdivided. It is the only mountainous portion of the State in which the strata are of later age than the Lower Silurian. It might be divided into (1) the folded, southeastern portion and (2) the deeply dissected Catskill plateau area.

NEW YORK-PENNSYLVANIA PLATEAU PROVINCE[2] (Fig. 4).—West of this, and occupying fully one-third of the State, is a great plateau region (Figs. 41, 87 and 96), deeply dissected by numerous broad river valleys. It is made entirely of Devonian rocks, mostly upper Devonian shales and sandstones, in which, however, there are some strata of limestone. The strata of this province are in a nearly horizontal position,[3] which determines the extensive plateau character of the province, a feature which extends southward, across the Pennsylvania line, along the western base of the Appalachians. Throughout the New York section of the plateau, the hilltops frequently rise to elevations of 1,500 to 2,000 feet, and their average elevation above sea-level cannot be less than 1,000 to 1,200 feet. From the valleys the region does not resemble a plateau, but rather a mountainous country; for the hills often rise to heights of 1,000 to 1,200 feet above the low valleys (Fig. 41). But from the tops of the hills, one is able to see that it is really a plateau region very much cut by stream action, and carved by denudation, into a maze of hills, many of which are capped by the harder layers of the nearly horizontal strata.

Considered as one great, dissected plateau, its surface undulates somewhat. Where the branches of the Susquehanna head against the headwaters of the Finger Lake streams, the plateau level is somewhat depressed.[1] It sags in the middle (Fig. 2), being higher near the western base of the Catskills and lower in the Finger Lake region; then, rising again, it reaches a high elevation in Cattaraugus County, in western New York. Beyond this, in Chautauqua County, and westward in Pennsylvania, the plateau level again descends. Excepting near the Catskills, the highest portions of this plateau are in Cattaraugus and Allegany counties in New York, and the adjoining counties of McKean and Potter in Pennsylvania.

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[1] An escarpment is a steep slope separating two more level areas. It is usually caused by a hard layer of rock in approximately horizontal position.

[2] Mather, Geology of New York, Part I, 1843, 317-365; Hall, same, Part II, 1843; also Williams, Bull. 80, U. S. Geol. Survey, 1891, Washington.

[3] There are some gentle folds and faults. See Hall, Geology of New York, Part IV, 1843, 163; 213; Williams, Proc. Amer. Assoc. Adv. Sci. XXXI, 1882, 412.

On its northern face the plateau ends in an escarpment, which, though irregular and somewhat serrated, is commonly quite pronounced. Its position in the east is determined by the hard Helderberg limestone (Fig. 24);[2] but in the extreme west it is located where hard shales overlie lower fragile beds, though its position is possibly determined by a bed of conglomerate now almost completely removed (see p. 97). Along the Erie shore, near the boundary between New York and Pennsylvania, the escarpment is about two or three miles from the lake; but toward the east, the escarpment recedes from the lake. In some cases the slope is very abrupt, and in Chautauqua County it ascends to a height of 500 feet in a very short distance. The escarpment is less distinct in Erie County, but becomes more pronounced toward the east, in Seneca and Cayuga counties, while still further east it becomes sufficiently high to form the "Helderberg Mountains." Therefore, for some distance, the northern boundary of the Plateau province, as well as that of the Catskill region (p. 8), is a single deposit of limestone, which forms an escarpment in some places rising a thousand feet above the lower plain.

LAKE SHORE PLAINS PROVINCE.[3]—At the base of the escarpment, north of the plateau, lies a plain. In the west, along

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[1] See Lincoln, Amer. Journ. Sci. XLIV, 1892, 290.

[2] Vanuxem, Geology of New York, Part III, 1842, 24; Darton, Report 47, New York State Museum, 1894, 394–396; 427–428.

[3] Hayes, Amer. Journ. Sci. XXXI, 1837, 241–247; Vanuxem, Geology of New York, Part III, 1842, various pages; Hall, Geology of New York, Part IV, 1843, various pages.

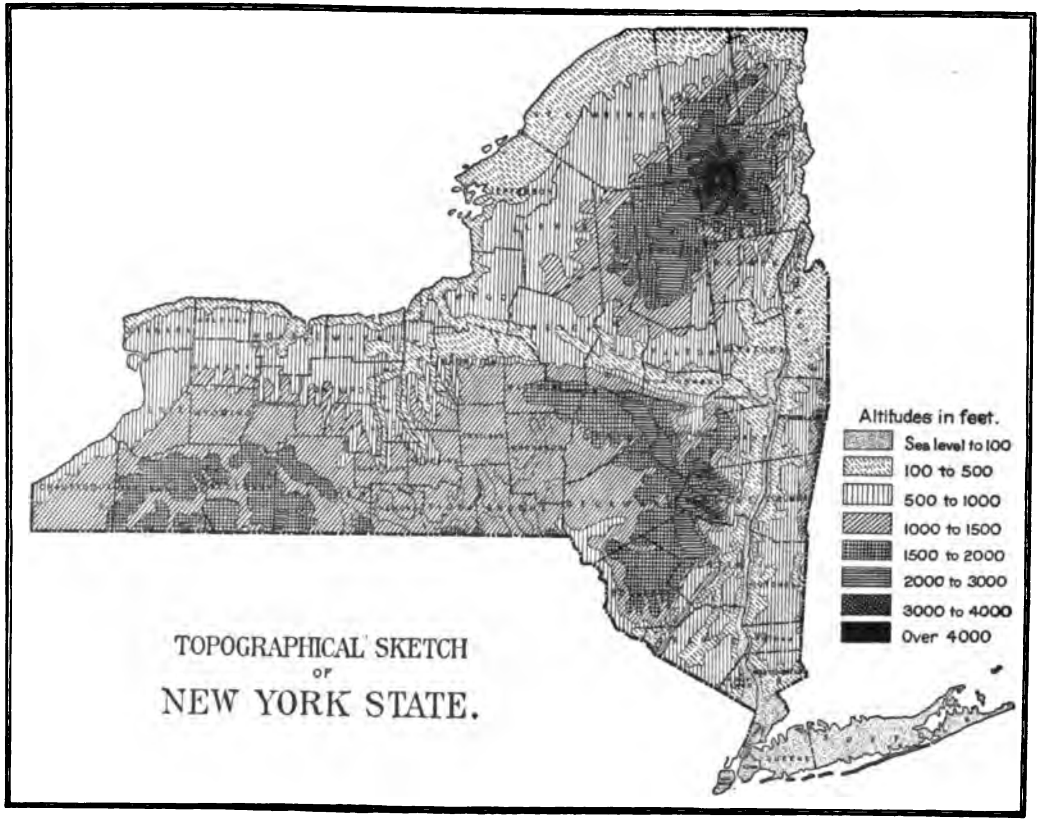
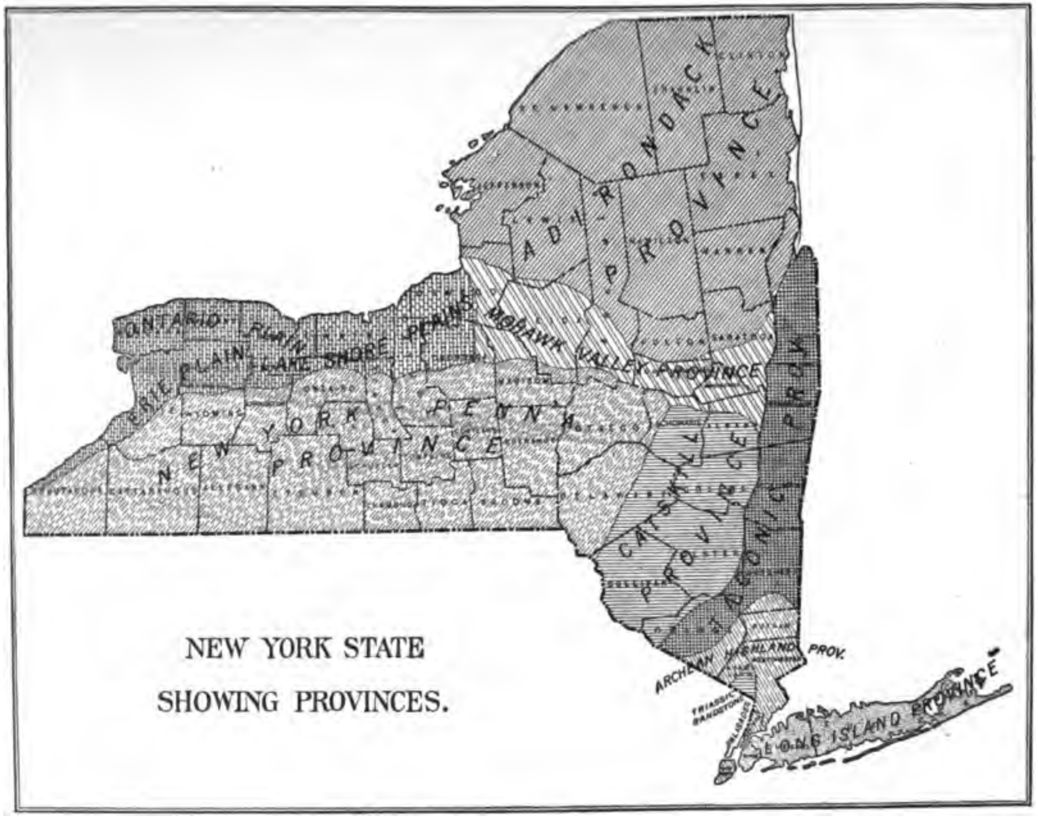


FIG. 3. Based upon the State Weather Bureau map.



NEW YORK STATE
SHOWING PROVINCES.

Fig. 4

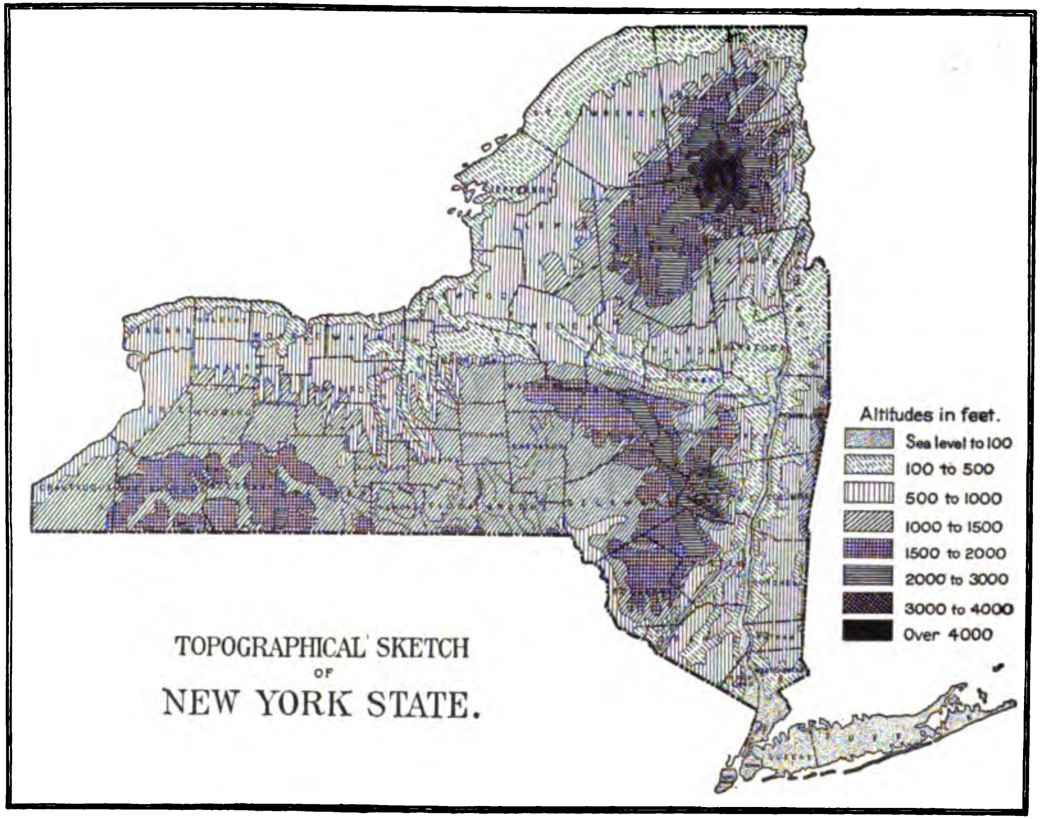
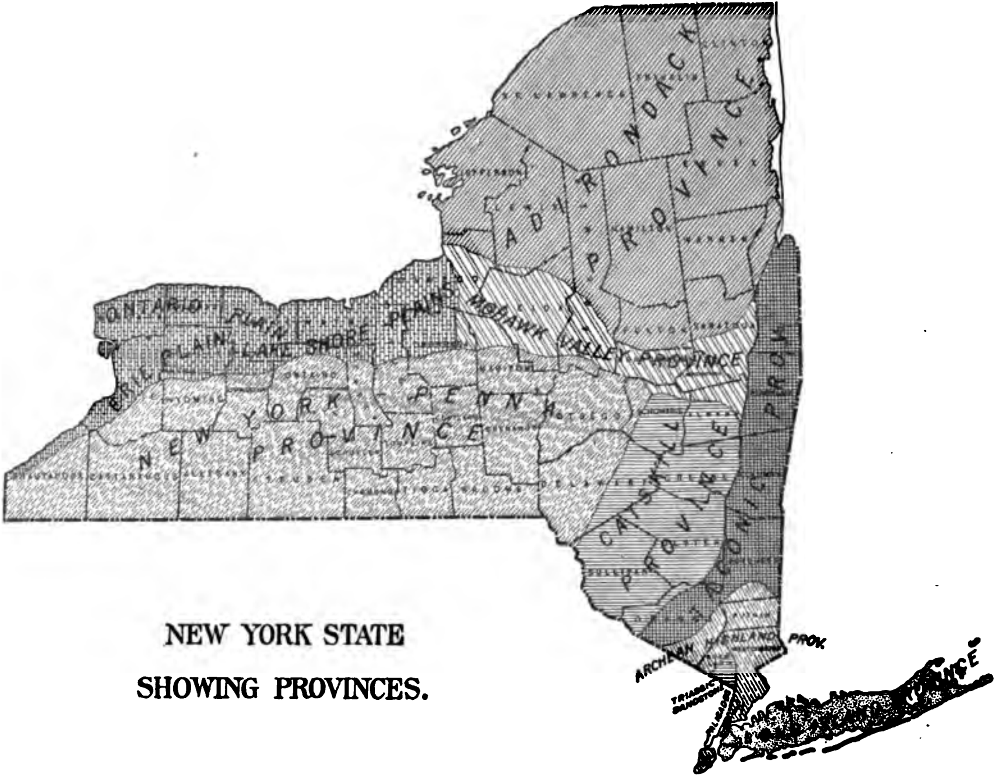


FIG. 3. Based upon the State Weather Bureau map.



NEW YORK STATE

SHOWING PROVINCES.

FIG. 4

the several divisions proposed. It is a nearly circular area of metamorphic and igneous rocks, mainly gneisses, granites, gabbros, norites and other plutonic or very much metamorphosed rocks. This area of crystalline rocks is surrounded by a collar of sedimentary strata of Lower Silurian and Cambrian age (Fig. 5), which, though not so much metamorphosed, nor so greatly disturbed in position, are nevertheless to be considered a part of the Adirondack province. In this area, therefore, is included the lower, hilly land which borders the St. Lawrence and the western base of the Adirondacks along the Ontario shore, as well as the hilly section on the southern boundary and that along the shores of Lakes George and Champlain.

The central and typical part of the province consists of a series of grand mountain masses, usually with flowing outlines (Figs. 6 and 8), and rising in several places to a height of over 5,000 feet, while Mt. Marcy,[1] the highest peak, reaches an elevation of 5,379 feet above sea-level. The east central portion is a central divide region, from which the streams radiate outward in all directions. In their course they are often very much disturbed by glacial deposits, and hence lakes are extremely abundant in these mountains.[2]

SUMMARY STATEMENT OF GEOGRAPHIC PROVINCES (Fig. 4).—Thus New York may be divided into eight provinces, every one of which, except the last two, is only partially in this State. These are:

(1) The Long Island area, which is the northeastward continuation of the Tertiary and Cretaceous plains of New Jersey, and is composed of soft rocks covered by thick deposits of glacial drift. (2) The Gneissic Highland province, which typically is made of highly metamorphosed rocks, folded into complex positions and with a general northeast and southwest strike. This may be subdivided into (*a*) the low hilly coastal portion; (*b*) the Palisade

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[1] See Emmons, Geology of New York, Part II, 1842, 218; Colvin, Trans. Albany Inst. IX, 1879, 11-26.

[2] Emmons, Geology of New York, Part II, 1842, 171; 213-214; 415-416; 422-427.

range; (*c*) the Triassic sandstone plains; (*d*) the true Gneissic Highlands, each of which extends from New Jersey into New York, while the areas of metamorphic rock extend northeastward into New England. East of this is (3) the Taconic province, a region of shales, slates, schists, limestones, etc., forming a valley in the southern part, but rising in the form of true mountains in the northern more highly metamorphosed portion. This province also crosses the southern part of the State, entering it from New Jersey and passing into Connecticut, Massachusetts and Vermont. Further west is (4) the Catskill province, which is the northeastern extension of the Appalachian folds and of the Appalachian plateau which skirts the western base of these mountains. While in some places the rocks are tilted, in others they are nearly horizontal, in each case being sandstones, conglomerates, limestones and shales. This province is bounded on the north by the Mohawk Valley area and on the west by (5) the New York and Pennsylvania Plateau province, into which it gradually and imperceptibly merges. In the plateau region the rocks are all Devonian, and mostly upper Devonian, while their position is horizontal or nearly so. This is faced on the north by an escarpment, at the base of which lies the (6) Lake Shore Plains province, in which the rocks are also horizontal; but, instead of being a deeply dissected plateau, the plain is remarkably level, rising to no great height above the surface of the lakes. In the west this province is double, consisting really of two plains separated by the Niagara escarpment; but in the east it becomes less level, where the two plains unite to form one by the disappearance of the escarpment. This then becomes more and more hilly toward the east and finally disappears in (7) the Mohawk Valley province, which is a hilly valley region, set between the Catskills and the great Plateau province on the one side and (8) the Adirondack province on the other. The latter province is the most mountainous as well as the highest portion of the State. It is essentially a New York province, although a very small part of its northern border extends into Canada.

The most typical provinces are the Adirondack and the Plateau areas. Omitting Long Island, one might with simplicity divide the State into but four provinces: (1) the Eastern folded region, extending from the Sound to the base of the Catskills; (2) the New York-Pennsylvania Plateau province, including the Catskills proper; (3) the Lake Shore Plains; (4) the Adirondacks, using the Mohawk River as a boundary line between the second and fourth provinces. We then have two areas of folded and contorted rocks (1 and 4), occupying rather more than one-third of the State, and two areas (2 and 3) of nearly horizontal strata. In the higher folded parts the rock structure is complex, the topography quite irregular, and the scenery is beautiful, particularly in the Adirondack portion. In the two areas of nearly horizontal strata, the scenery is usually less varied, though sometimes mountainous, notably in the Catskills and in Cattaraugus County. With decrease in ruggedness, the value of the land for agricultural purposes increases; and so the best of the agricultural land is situated on the plateaus and plains, particularly in the lower and more level lands near the lakes.

DRAINAGE OF THE STATE

LAKES.—The drainage of the State is greatly interrupted by lakes, some of which present very interesting and even remarkable features. The lakes vary in size from Ontario, whose greatest length is 190 miles with a width of 55 miles, to tiny ponds; and they vary in depth from mere shallow pools to Ontario, which in one place reaches a depth of 491 feet below sea-level.[1] There are various types of lakes (Chapter VI); but the prevailing feature throughout the State is the linear form, so typically illustrated in the group of Finger Lakes[1] which occupy the central depressed portion of the great Plateau province, though not less so in Lakes Chautauqua, George, Champlain, and many of the Adirondack lakes. For the most part these lakes are plainly river valleys in which water has been made to collect because of their local transformation to basins.

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[1] Being 738 feet deep and the surface being 247 feet above sea-level.

While the lakes of the State are well scattered over its entire area, they are, excluding Lakes Erie and Ontario, bunched with especial abundance in three parts of the State, namely, (1) the Finger Lake region of the Central Plateau, (2) the Adirondacks and (3) the mountainous and hilly southeastern part of the State, including the Catskills. In these areas, and particularly in the Adirondacks, lakes are present in great numbers. Among the Adirondacks alone, there are many hundreds, great and small, besides a large number that have been filled and changed to swamps and meadows.

THE ST. LAWRENCE.—The water that falls within the boundaries of New York passes outwards in all directions.[2] Not far from one-half of the State, and more than one-half of the Adirondacks, is drained through the St. Lawrence River. The divide between the St. Lawrence and the rivers that drain southward passes irregularly from northeastern to western New York, passing out of the State in only one place, namely, in the middle western portion, where the Genesee rises in Pennsylvania. The part of the State that drains into the St. Lawrence system sends its waters to that river through numerous streams, most of which are very small. There are many hundreds of these that enter the Great Lakes, Lake Champlain, or the St. Lawrence directly. The only two that are of large size are the Genesee, which rises in Pennsylvania, and flows northward, entering Ontario near Rochester, and the Oswego, which carries the waters of the Finger Lakes of central New York. The irregular divide between the St. Lawrence and the southern drainage is sometimes far from the St. Lawrence or from the Lakes; but in one place, in Chautauqua County, in western New York, it is within sight of Lake Erie and at a distance of not more than ten miles from the lake shore.

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[1] Vanuxem, Geology of New York, Part III, 1842, 237-242; Hall, Same, Part IV, 1843, 321; 405-408; Lincoln, Amer. Journ. Sci. XLIV, 1892, 290-301; Brigham, Bull., Amer. Geograph. Soc. XXV, 1893, 16; Tarr, Bull. Geol. Soc. Amer. V, 1894, 339-356.

[2] Ballou, Amer. Nat., XIV, 1880, 139-140.

Not only are the tributaries of the St. Lawrence system frequently interrupted by lakes, but the main stream itself has the same features even more markedly developed. The main valley includes a series of lakes, the Great Lakes, of which two, Erie and Ontario, are partly within the boundaries of New York. In the case of Ontario the valley is transformed to a lake for a distance of about 190 miles, with an average breadth of not far from 40 miles. Connecting Lakes Erie and Ontario is the Niagara River, with its wonderful falls and gorge (Chapter IX). At the other end of Ontario, the waters emerge through a region almost as remarkable as the gorge through which they enter it. The lake gradually merges into a river, its channel being clogged and dotted by scores of islands (Fig. 165). The outlet of Ontario is at first a great bay, gradually becoming a river only after passing over a distance of many miles, in the course of which it divides and ramifies between low rock hills, causing the Thousand Islands.[1]

THE HUDSON.—Next in area is the Hudson drainage, including its single great tributary, the Mohawk, which enters from the west. The eastern divide of this river system is very nearly the boundary between New York and New England, now entering these border States, again entering New York. A portion of the Catskills and the Adirondacks drain into the Hudson. This is the single large stream which is really a New York river. Unlike any other, it rises in the State, flows entirely within its area

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Bigsby, Phil. Mag., Ser. IV, Vol. V, 1829, 1-15; 81-87; 263-274; 339-347; 424-431.

and enters the sea within the State boundaries. With the exception of a very little water received from the bordering States of New Jersey, and New England, the Hudson obtains all of its supply from New York.

The Hudson is notable for its remarkably straight course from the rectangular turn at Sandy Hill to the Sound (Fig. 2), and also for its deep valley with steeply rising rock walls. The influence of the tide is felt even above Albany. It is navigable as far as Troy, but above the mouth of the Mohawk the river is small and unimportant; and if it were not for the fact that the tide holds back the water of the Hudson, it would never have become the important commercial artery that it now is.

OTHER DRAINAGE SYSTEMS.—The Delaware River rises in New York State, draining a part of the Catskills and the neighboring region. Its waters enter the Atlantic through Delaware Bay. Further west the Susquehanna tributaries have their headwaters on the southern side of the St. Lawrence divide. These drain very nearly one-fourth of the State, competing with the St. Lawrence throughout the greater part of the central plateau. By the time the Susquehanna leaves New York, it has become a large river. The waters are carried southeastward into Chesapeake Bay. Farther west, in Cattaraugus and Chautauqua Counties, the Allegheny River enters New York; and, after a short course within the State, it reënters Pennsylvania, thus leading the waters of a small corner of the State into the Gulf of Mexico, through the Ohio and Mississippi.

From this it is evident that the State of New York is a great divide region, contributing water to no less than five well-known river systems, the St. Lawrence, Mississippi, Susquehanna, Delaware and Hudson, only one of which enters the sea in the State, or is even in large measure within its boundaries. A very small part of the drainage of the State passes directly to the sea through small streams in New Jersey and Connecticut. Water falling upon a part of the New York divide may enter the

St. Lawrence, while a short distance away it would find before it a much longer journey southward to the Gulf of Mexico.

Gorges and Waterfalls (Chapter V).—In many of the northern States, waterfalls and gorges are notable and common features; but of none is this more true than of New York. Many of the streams, particularly those of the central plateau region, flow for a part of their distance in gorges in which they are interrupted by falls and rapids. Niagara is a type of these, which, though larger and more wonderful than its fellows, finds its counterpart in hundreds of places in other parts of the State. A consideration of the causes for this peculiarity, as well as of the other physiographic features of the State, will be found on later pages.

Peculiar Importance of the New York Drainage.—Leaving out of question the æsthetic aspect of the drainage, for which the lakes, gorges and falls of New York are justly noted, and the commercial value of the water for power, there are several features of New York drainage which have had a remarkable influence upon the development of the State. A navigable river, the Hudson, reaches into the heart of the State, extending far up toward Lake Ontario. Indeed, with a canoe, but a short portage is needed to reach that lake. As soon as the Indians were overpowered, these waterways served as a natural pathway into interior New York, and indeed to the West.

As the necessity for transportation to and from the interior settlements increased, it became possible, because of the great natural facilities, to add a system of artificial waterways to the readily navigable Hudson and the large lakes. So New York is ramified by canals, the most remarkable of all being the Erie, which, emerging from Lake Erie near Buffalo, passes along the upper member of the Lake Shore Plains province, descends to the lower plain and then extends over the level surface to the divide at the head of the Mohawk, down the valley of which it passes to the Hudson. This canal and its tributaries have done more toward the early development of the resources of the State of New York than almost any other feature; and both the main canal and the branches depend for their location upon the peculiar configuration and drainage of the State.

By means of the natural and artificial waterways, it is possible to reach into the very heart of the country. For a while it seemed as if railways had done away with the necessity and value of this canal system; but by broadening and deepening the canals, their future seems to promise as much as their past has accomplished. No canal in this country offers better facilities for enlargement, or greater need of this improvement, than does the Erie, and it may safely be predicted that this will be done.

PHYSIOGRAPHIC FEATURES ILLUSTRATED IN NEW YORK

About New York as a center it would be possible to build a complete physical geography. Within its boundaries are illustrated very nearly all of the important groups of physiographic features. Among rivers there are various forms and types; and of lakes there are both an abundance and a variety of kinds. Of coastline features illustration is furnished not merely along the seashore of Long Island and the very southernmost angle of the State, but also along the shores of the Great Lakes, and, in a smaller way, along the shores of the smaller bodies of water. Mountains find illustration in several types; and, although volcanoes are absent, lava rocks are found in the Palisades of the Hudson and in various other parts of the State.[1] Plateaus and plains cover more than one-half of the State and they exhibit varied features, while instances of cliffs and escarpments abound. Besides these greater earth features, there are many smaller ones, the most notable of which are those that have resulted from glacial action. There are terraces, ancient shore lines, various kinds of glacial hills, and, indeed, illustrations of most of the glacial features. In later pages these are taken up for consideration. There are few States which offer within their own boundaries so rich an assemblage of physiographic illustration.

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[1] See references on p. 12; also Kemp and Marsters, Trans. New York Acad. Sci. XI, 1891, 13–23.

GEOLOGICAL DEVELOPMENT OF THE STATE

DEPOSIT AND FOLDING.—The Adirondacks are distinctly the oldest large area in New York, the only possible competitor being the crystalline highland region of the southeastern corner of the State (the real gneissic part of the Highland province), where the Archean rocks of the New Jersey Highlands extend across the New York boundary. At the beginning of the Paleozoic, both of these areas of crystalline rock were mountainous lands facing a sea which stretched away to the westward, and beneath which the rest of New York State was submerged. The southwestern highland mountains extended northward into New England; and toward the east they probably formed land far beyond the present coast line. This mountain system extended from New York southwestward into the southern States. Its eastern extension is unknown; but to the west was a great sea occupying the site of the Mississippi valley and extending northward beyond New York. Whether the Adirondacks and this highland mountain range were ever connected, and what was the actual former extension of the two areas, cannot be told in the present state of geological knowledge. The record of much of the early history has been hidden beneath the strata of later age.

However, in the very early Paleozoic, the waves of the sea beat against the western base of the southern highlands and these were then, at least, separated from the Adirondack area, which was at that time an island in the Paleozoic sea. This is shown to be true by a ring of

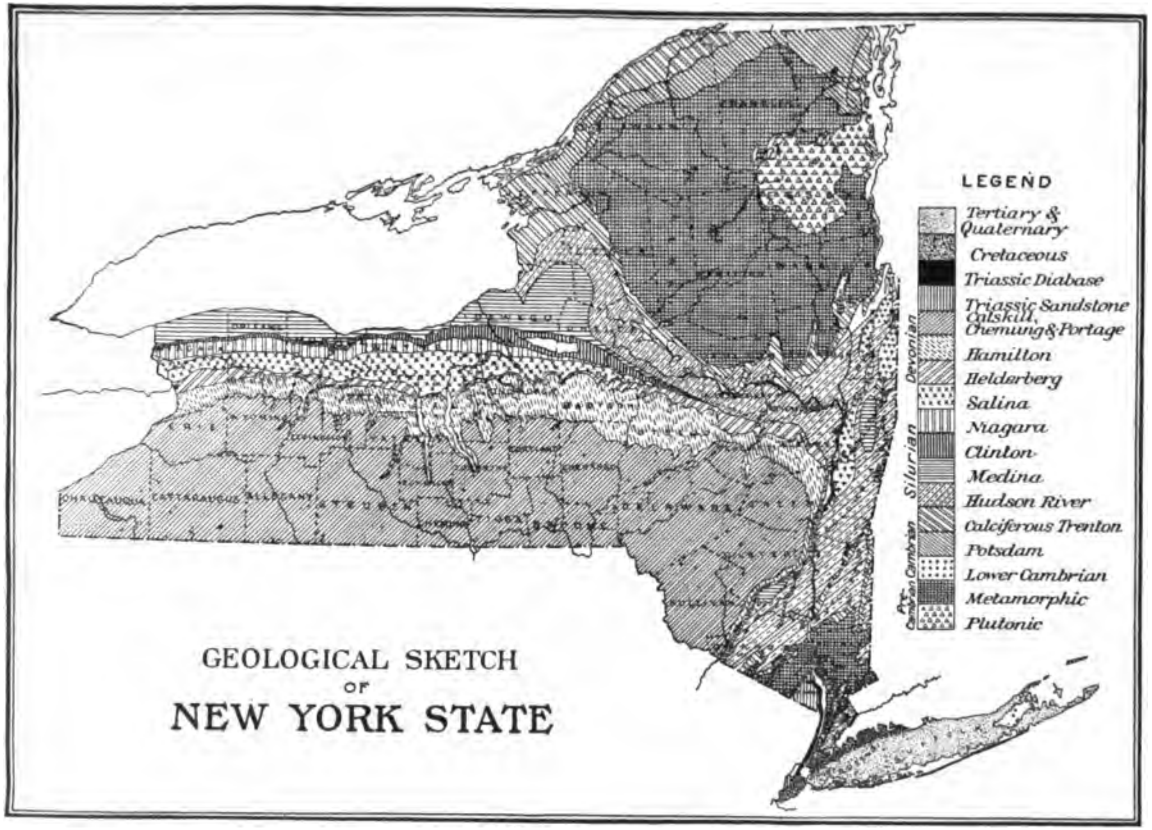

FIG 5. Based upon the State Museum map.

early Paleozoic sedimentary rocks, which practically surround the Adirondacks, and in which fossil beaches can now be plainly detected. Later folding has doubtless affected the Adirondacks, and it is also probable that parts of these mountains have since that time been submerged; but their main post-Archean history is one of long-continued denudation, as a result of which the elevation has been greatly reduced. Throughout much of the Paleozoic, and apparently throughout all of the post-Paleozoic time, these mountains have been subjected to constant denudation. The structure and detailed history of the Adirondacks are very obscurely understood, and little except the most general facts are at present known concerning it.

Next in the development of the State came a great overturning of the rocks along a line parallel to and near the crystalline highlands of the southeast. Indeed, these were involved in this folding, which profoundly influenced the southeastern portion of the State and all of western New England and eastern New York. From the neighborhood of Quebec, southwestward as far as Virginia, and apparently beyond, this period witnessed the growth of a great mountain system, which has been called the Taconic system by reason of the fact that the Taconic Mountains, of the New York-Massachusetts boundary, have furnished good evidences of this system of folding. The rocks involved in the overturning include the older crystalline pre-Paleozoic rocks and the Cambrian and Lower Silurian sedimentary strata; and, as a result of the mountain growth, these have been extensively folded and faulted. Since rocks of Upper Silurian age rest unconformably upon the edges of these uplifted strata, the age of the Taconic Mountain uplift is placed near the close of the Lower Silurian. By the folding the rocks were also extensively metamorphosed, the limestones often being changed to white marble, the sandstones to dense quartzite, the shales to slates, etc.; and in some places the metamorphism has gone so far that the original rocks are now changed to schists and even to gneisses.

The folding and faulting were more intense in the northern part of the State than near the New Jersey line, and more in the eastern than in the western part. Hence the rocks are more metamorphosed, and therefore more durable in the northern than in the southern counties. In the south, in Orange County, the folded rocks are bounded on both the east and the west by harder strata, and, therefore, denudation has lowered them into the condition of a valley. The real Taconic ranges, near the New York-Massachusetts boundary, and their continuation along the Green Mountains of Vermont, furnish illustration of good-sized mountains. This is especially true of those which, like Mount Greylock in Massachusetts, consist partly of quartzite or other durable rock. Since their formation these mountains have been much worn, and there is every indication that they were once very lofty ranges. Among them the folds are often overturned, and there are numerous illustrations of overthrust faults where the rocks have broken along a nearly horizontal plane, and the upper beds have been moved bodily over the lower. Some of these faults are of great extent.

Toward the west the mountain folding disappeared; but how far it extended cannot be told, since later rocks cover the folded strata. It certainly extended as far west as Little Falls, for the folds on the southern margin of the Adirondacks are of this age.

During the remainder of the Silurian and Devonian times, that part of New York which lies outside of the Adirondacks and the southeastern provinces of folded rocks, lay beneath the sea, at least for the greater part of the time. This sea was on the average a shallow one, and it received contributions of sediment from the Adirondacks, the Taconic ranges, and also probably from the Canadian highlands. Shallow water conditions are almost everywhere indicated among the central New York strata; and the very coarseness of the deposits among the Catskills shows that land was near by at the time these beds were deposited. During these geological periods, there was deposited in this sea a depth of sediment which in the Catskills is fully 10,000 feet; in central New York, in the Genesee River valley, not less than 7,000 feet; and in the highlands of Chautauqua County, some 6,000 to 6,500 feet.[1] During this time, the straits that had connected the New York sea with the sea north of the Adirondacks became closed. The beginning of the St. Lawrence valley along the northern border of New York had been determined very early by a depression into which the sea entered.

While the Silurian and Devonian sediments were being laid down, there were evidently numerous minor changes in the land and water; but the average condition was one of slow subsidence of the general area which was beneath the sea. Beds of shale and limestone were being deposited over much of the State, although sandstones and conglomerates were formed in some places near shore lines. During the Salina division of the Upper Silurian, conditions prevailed over central New York as a result of which extensive beds of rock salt were accumulated between beds of shale, the total depth of the salt strata being from 50 to 150 feet.[2] The reason for these salt beds is apparently a shallowing of the New York sea accompanying a broad general uplift in Ohio and neighboring States, which formed what has been called the Cincinnati arch. Before this the conditions had favored the deposit of the thick Niagara limestone in clear and possibly moderately deep water. By the shallowing of the sea this part of the State may have become a great salt vat, reached by the sea and subjected to evaporation, so that beds of salt were precipitated and later covered by beds of very fine mud. After this the sea again entered this portion of the State, becoming clear, open water, perhaps of considerable depth, and certainly free from land sediment. During this time another series of limestone beds, the Helderberg and Corniferous, which extend from near the Hudson to Buffalo, were accumulated in the sea.

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[1] Communicated by Prof. C. S. Prosser. For records of sections in New York, see Prosser, Proc. Amer. Assoc. Adv. Sci. XXXVI, 1887, 208–9; Amer. Geol. VI, 1890, 199–211; Proc. Rochester Acad. Sci. II, 1892, 49–104; Bull. Geol. Soc. Amer. IV, 1893, 91–118; Fairchild, Proc. Rochester Acad. Sci. I, 1891, 182–186; 215–223.

[2] Eaton, Amer. Journ. Sci. VI, 1823, 242–243; Smith, Amer. Journ. Sci. XV, 1829, 6–12; Phil. Mag. VII, 1830, 198–201; Vanuxem, Geology of New York, Part III, 1842; Hall, same, Part IV, 1843; Gibson, Amer. Journ. Sci. V, 1873, 362–369; Newberry, Trans. New York Acad. Sci. IV, 1887, 55–57; Wright, Science, VIII, 1886, 52; Newberry, Trans. New York Acad. Sci. IX, 1889, 39–45; Hall, Luther and Clark, Report 47, New York State Museum, 1894, 203–383.

After this, throughout the Devonian, the conditions favored the deposit of extensive beds of shale, which in central New York often reached a depth of more than 3,000 feet. These vary from fine textured clay-rocks to sand layers, and from real clay to impure limestone and even, in one or two cases, to pure beds of limestone. In the east, near the Taconic ranges, the deposits in this sea were mainly sandstones and conglomerates, evidently because this was near the coast line. Here, in the region of the Catskills, the sandstones are between three and four thousand feet thick, and this is the main determining factor for the existence of the Catskill Mountains. Their location, therefore, depends primarily upon the former existence of a shore line supplied with quantities of sand and pebbles from nearby mountains.

Conglomerates are also found in the extreme southwestern part of the State, these being remnants of a bed of upper Devonian conglomerate. They have attracted considerable attention because of their fancied resemblance to ruined cities; and in places where the conglomerate beds have broken along the joint planes, and then tumbled apart as a series of huge blocks, they have been given the name "rock cities" (Fig. 44).[1] The blocks have been undermined by the action of denudation, which eats away the softer underlying shales and allows the huge fragments to assume various attitudes. It is probable that conglomerate has recently extended over a considerable part of the high southwestern plateau; and perhaps it has been the cause for the great height of this section, the overlying conglomerate cap protecting the soft shales from rapid denudation.

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[1] Hall, Geology of New York, Part IV, 1843, 284–285; Ashburner, Penn. Geol. Survey, Report R., 1880, 49–78.

Whether the Carboniferous ever extended into New York State or not, and, if it did, how far it extended, are questions now impossible to answer; but there seems little reason to doubt that the Carboniferous strata did extend for at least some distance into the State. Since the Carboniferous time, throughout the entire State, there has been an almost uninterrupted condition of land exposed to the air; and during this time much rock material must have been removed. Throughout the higher parts of the central plateau the rocks are of the upper Devonian age; and, unless some Carboniferous strata existed there, having since been removed, we must marvel at the minute amount of work done by denudation throughout all of the post-Paleozoic time. Therefore we seem warranted in holding the theory that the Carboniferous did extend well into New York, possibly covering the entire plateau.

FINAL UPLIFT.—Perhaps early in the Carboniferous time, certainly before the close of that period, the State of New York was raised above the sea, a position which, so far as we know, it has uninterruptedly maintained ever since, excepting perhaps in some very limited localities and for a short time, as for instance along the Champlain[1] and Hudson River depression. This elevation was associated with the uplifting of the Appalachian Mountains; and although at that period there was no extensive mountain folding within the State of New York, the great series of strata were raised as a general plateau uplift with some minor folds. The rocks of the plateau itself, and of the Lake Plains to the north of it, are so upraised as to dip very gradually to the south. Near the central part of the plateau, along the shores of Lake Cayuga, and elsewhere within the State, the strata are thrown into gentle undulations with east and west axes. Near the boundary of New

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[1] Emmons, Geol. of New York, Part II, 1842, 127-134; 283-284; Kellogg, Science, XIX, 1892, 341.

York and Pennsylvania, east and southeast of Binghamton, the effect of the mountain folding is plainly seen in the rocks; and at the angle of junction of New York, Pennsylvania and New Jersey, the mountain folds are quite pronounced. Among the Catskills, while there is some folding, the real cause for the ruggedness of the mountains is the presence of the very massive and durable sandstone, which in some places has a depth of not less than 3,000 feet. Because the upper Devonian in this part of the State is sandstone rather than shale or sandy shale, the Catskill region rises in a series of prominent elevations which are carved into very mountainous outlines. There has also been greater uplift in this section and some folding; but denudation is the really potent cause for the carving of these mountains.

There are no means of telling in what form the uplift of the State left the surface. However, from the dip of the rocks it seems probable that the greatest elevations were in the north and east. The Adirondacks seem to have continued, as they had previously been, a great central divide, from which the streams radiated in all directions. The Taconic ranges must have served to prevent the flow of New York waters toward the east, just as they do at present. The greater uplift of the Catskill area may have determined some of the drainage approximately along the course of the Hudson valley, while in the trough between the Catskills and the Adirondacks, the Mohawk naturally developed. If the St. Lawrence valley in its present site existed early in the history of the State, there must have been drainage toward it, and there is very little reason to doubt that some of the water of the State thus found its way northward.

The tilting of the rocks to the south must have determined this as a direction to be pursued by much of the drainage. Before we can be certain of what has happened to the New York rivers we must first learn more about the early history of the streams in the Pennsylvania region. What has led the Delaware and Susquehanna waters across the Appalachians through their remarkable water-gaps? Was the tilting of the rocks beneath the plateau of central New York accomplished at the same time as the uplift of the Appalachians, or has it been a later development? If the former, then the greater part of the drainage of the western half of the State must have been toward the south; if the latter, this does not of necessity follow. It seems that the topography and drainage indicate the first rather than the second. North-flowing streams have an advantage in cutting their valleys in rocks that dip to the south.[1] By the law of monoclinal shifting,[2] as the surface wears down, the divides should gradually retreat to the south; and so the north-flowing streams would constantly gain territory at the expense of those which were flowing toward the south. As a matter of fact, the north-flowing streams of New York have not pushed their headwaters very far back into the plateau, apparently not so far as they would have done if they had been north-flowing streams at the beginning of the uplift of the plateau.

Another question is whether the rocks were at first raised to their present height. Here again the answer must be somewhat doubtful, but apparently in the negative. Had the land originally been elevated to its present height, it should be denuded vastly more than it has been. Even granting a complete covering of Carboniferous rocks for the central plateau, the time that has elapsed since the close of the Carboniferous would have allowed more than 10,000 or 15,000 feet of strata to be removed. Besides this, the drainage systems indicate later elevation, as do other facts from outside of the State.[3]

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[1] Of course this applies to any streams heading in a tilted region and flowing in opposite directions.

[2] This is, briefly, that in the lowering of the surface of a country under the action of denudation, if the rocks are inclined, the divides will migrate in the direction of the dip. See Gilbert, Geology of the Henry Mountains, Washington, 1880, 129 and 134; also Tarr, Elementary Physical Geography, 274.

[3] Notably the fossil faunas of Mesozoic and early Tertiary ages, which seem to prove the existence of lowlands in the northeastern part of the country. Also in the valley of Lake Champlain, deposits of Tertiary age prove a depression for this region.

The history seems to have been that of an uplift at the close of the Carboniferous, continued now and then, so that considerable denudation has in the meantime been possible; and then, in the mid-Tertiary, there came a decided uplift which allowed all the rivers of central New York to cut deep valleys; but this uplift occurred long enough ago to admit of sufficient broadening of the valleys to produce a mature type of topography. With this uplift something like the present condition of drainage was introduced, although in the details many changes have been introduced by the ice invasion.

POST-PALEOZOIC DENUDATION.—As a result of this extensive denudation, any rocks that may have overlaid the Devonian have been removed; and, in a great part of the area, the Devonian and older strata are trenched deeply by valleys, so that the plateau is very much dissected by deeply-cut valleys, particularly near the divides (Fig. 41). Although these are fairly well rounded, there remain great hilly masses between; thus but a mere beginning has been made toward the removal of the Devonian and older rocks.

In the progress of the denudation the plateau has naturally been attacked, not only by the streams that have trenched it, but also by wasting away from the north. If, as seems evident, there existed parallel to Lake Ontario a river with an east and west extension, from this valley as a base there would naturally be an attack upon the rocks of the plateau which lies to the south. The strata of this plateau, dipping toward the south, exposed their outcrop edges towards the north. The hard rocks protected the soft; but, as these were undermined, the hard strata retreated in the direction of the dip, always with a tendency to maintain an elevated position. An excellent example of this is seen between Rochester and Lewiston, especially near the latter place, where the hard Niagara limestone covers soft shales and determines the position of the bold Niagara escarpment. Where the hard Helderberg limestone outcrops, the same tendency exists, and here again an escarpment results. This very marked influence of the rock structure on topography, producing so precipitous a slope in a region whose elevation is not great, could only result when the action of denudation had produced moderate effects during its present cycle.

The time is not yet ripe for the announcement of the complex histories of New York rivers, and hence for the elucidation of the development of many of the main topographic features of the State. The remarks made above are merely suggestive and are thrown out only as hints. However, it is certain that rivers differing in kind from those of the present, and perhaps even with different courses, existed before the Tertiary uplift. After that uplift the streams cut down through the strata and carved their mature valley forms, perhaps not always in the courses which they formerly pursued.

ICE INVASION.— Then, as a last step in the development of the features of the State, came the Glacial Period (Chapter IV), which succeeded the Tertiary uplift, and during which practically the entire State of New York was covered with a thick sheet of ice. Why this came, how long it remained, and why and when it disappeared, are questions that do not now admit of definite answer. For some reason, possibly the uplift, from some source in northeastern Canada, an ice sheet spread out over New York, covering it as effectually as Greenland is covered by ice to-day. When this went away, the surface of the land, though in some particulars hardly affected, was nevertheless in many respects strangely transformed. Over the surface was strewn a sheet of glacial deposit of variable thickness;[1] some of the hills were planed down and rounded, others were built up; some valleys were deepened, others were more or less completely filled; some streams were turned completely out of their valleys, some only partly interfered with; and many valleys were locally transformed to lakes. The hundreds of lakes that dot the State were thus created, and even Lakes Erie and Ontario had their birth at the close of the ice period. The Falls of Niagara, and many other gorges and waterfalls, have also had their beginning as a result of the ice action. With the withdrawal of the glacier, the form of the lakes varied, finally assuming their present condition. The sea also rose higher than it does at present, and parts of the Hudson-Champlain depression were submerged; and then, finally, the conditions of the present came about. Many of the details of the physiography of the State are a result of this ice invasion, and some of these subjects will serve as special topics for discussion.

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[1] Mather, Geology of New York, Part I, 1843, 158–228; Hall, same, Part IV, 1843, 318–341; Chamberlin, Third Annual Report U. S. Geol. Survey, 1883, 347–379.

CLIMATE OF THE STATE[1] (Chapter XI).

Throughout the State of New York there is abundant though not excessive rainfall; but, as in the other eastern States, there is liability to occasional drought. The total precipitation in inches varies from 25–30 in the northwestern part of Niagara County, and in some places north and east of the Adirondacks, to 60 inches near the coast and on the slopes of the Adirondacks (Fig. 201). Over most of the State the rainfall ranges from 35 to 50 inches. There is a greater percentage of cloudiness near the Lakes than at a distance from them, and over nearly one-half of New York the sun is obscured for more than 60 per cent of the time during which it is above the horizon. In the southeastern portion of the State there is the least cloudiness.

The mean annual temperature ranges from 50° near the coast and 48° near Lake Erie, to less than 40° in the Adirondacks (Fig. 196). The mean temperature for July ranges between 72° on the coast and 70° near Lake Erie, to less than 64° in the high Adirondacks. In January it ranges between 30° at the coast and 26° on the Lake Erie shore, to considerably less than 16° among the high Adirondacks.[1]

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[1] See Turner, Fifth Annual Report of the State Weather Bureau of New York, Department of Agriculture, Albany, N. Y., 1894, 345–448; also Chapter XI, pp. 331–366, of this volume.

In the distribution of the isotherms there is much irregularity, for the influence of topography is very marked. It will be seen from this statement of temperatures that New York is peculiar in having high summer and low winter averages. However, it is not nearly so extreme as some of the interior States. For instance, St. Paul, Minnesota, has an average temperature of 72° in July and 8° in January; and St. Vincent, Minnesota, has an average of 65° in July and —10° in January. On the other hand, San Francisco has a summer temperature of 69° and an average winter temperature of 50°; choosing single months for the averages.

Since New York has such low winter and high summer temperatures, the climate of the two seasons corresponds with climates in widely differing latitudes. This has been so well stated by Mr. Turner[2] that I quote from his description as follows:

"The isothermal line of 70 degrees, which will be observed on the chart for July to pass from the Great Lakes over northern New York, extends thence eastward through New England to the vicinity of the coast, where it again turns toward the southwest, meeting the line of 70 degrees which appears over eastern Long Island. This isothermal then passes directly eastward over the Atlantic near parallel 40 degrees, intersecting the coast of Europe in northern Spain. Reaching the warmer land surface, it tends somewhat north of east through Central France, Austria, Central Russia and Siberia. Near the eastern coast of the latter country it turns southward through 20 degrees of latitude and passing to the Pacific over the Island of Japan, continues nearly eastward, meeting the coast of America in Central California. Thence it follows the meridian of 120 degrees west well northward into

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[1] For the upper portions of the Adirondacks there are no reliable data.

[2] 5th Annual Report, New York State Meteorological Bureau, Vol. II for 1893, 361-2.

British America before again turning to the southeast in the direction of the Great Lakes and northern New York.

"The line indicating 74 degrees in July passes from New York directly southward over the ocean until opposite Virginia; thence slightly south of east to Morocco in North Africa, where it turns northward to France; thence passes through southern Europe (north of the Italian peninsula) to the Black Sea, through central Asia at latitude 50 degrees, and near the coast turns southward to Japan. Diverging somewhat from the isotherm of 70 degrees, in its course over the Pacific, it touches America in Southern California, follows the Rocky Mountains northward to British America and thence takes a southeasterly direction to the Great Lakes and New York.

"In January, New York is to be classed with quite different regions of the globe from those named above. The isotherm of 15 degrees, which appears near the northern boundary of the State, passes thence over Labrador, the southeastern coast of Greenland and the Arctic Ocean. When well to the northward of Scandinavia it turns southeastward through Central Russia (passing north of St. Petersburgh) to the northern border of the Caspian Sea. Proceeding eastward to northern Japan and northeastward over the Pacific it reaches the southern coast of Alaska, when it again trends southward to South Dakota and finally passes north to the Lake Region to the St. Lawrence valley.

"The mean January temperature of 30 degrees (that of New York city) is found also in southern Newfoundland, Iceland and northern Norway. This isotherm turns sharply southward in the latter region and passes to eastern Germany, Austria and the northern border of the Black Sea, when its course becomes eastward to the Pacific. Like all the preceding lines it intersects Japan and thence passes northeastward to the Aleutian Islands. Following the American coast line to the border of the United States, it turns southeastward to Missouri and thence passes to the southern shore of the Great Lakes."

There are several interesting climatic peculiarities in New York. In general, the climate is that of an interior land area, though it is near enough to the seashore to be considerably influenced by the ocean. The prevailing winds are from the west[1] and the alternations of weather conditions are due to the passage of successive areas of high and low pressure from west to east, producing, as they travel onward, alternate conditions of clear, dry weather and cloudy, rainy weather.

In these respects New York is not unlike the other States of the north. During the passage of the clear anticyclonic areas of high pressure, cool or cold winds blow from the north and the northwest, in winter spreading a blanket of cold air over the land. While the stormy conditions of the low-pressure areas prevail, air flows in from the south. It then comes either from the Atlantic or the Gulf (the latter particularly in the western portion), and so brings moist, warm conditions to the State. With the coming of the south wind, rain and snow often fall, because the air, in moving northward, passes into colder regions and also rises over the plateau, thus being cooled down to the dew point, when precipitation must follow. When rain does not fall, the weather becomes warmer, in winter producing thaws, in summer causing heated terms.

These normal conditions of weather change are somewhat interrupted by topographic features, only a few of which can be mentioned. That part of the State which is most distinctly influenced by the ocean is the vicinity of New York City and Long Island. There the winters are warmed and the summer heat moderated by the influence of the water. The mean annual temperature is higher and the range in temperature less than in other portions of the State. Also in this part of the State the rainfall is greater than in other portions, with the probable exception of the high Adirondacks. During the summer the heat is frequently tempered by the cool sea breezes.

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[1] This is often well illustrated in orchards, where the trees are all seen to incline towards the east.

The coldest and most variable portion of the State is the high Adirondacks, which, though cool in summer, become very cold in winter. Here there is much snowfall and the climate is distinctly that of mountains.

An influence very much like that of the ocean is exerted upon the climate of New York by the waters of the Great Lakes (Figs. 194 and 195). They serve to temper the summer heat and to moderate the winter cold. When a cold wave overspreads the region, the temperature of the United States side of Lako Ontario may be 10° or 20° higher than it is on the Canadian side. This influence of the Great Lakes holds back the spring-time development of plants by the presence of the cold water; and hence vegetation is not so liable to suffer from late frosts as it is in more distant regions where development has proceeded farther. In the autumn the warm body of water, with its temperature raised through the summer, does not cool so quickly as the land; and thus, by its presence, the water prevents frosts near the lake shore and lengthens the growing season.

The influence of the water of the Great Lakes is felt very nearly all over the State, for many of the winds must blow over their surface before reaching other parts of the State; but the really noticeable influence is confined to a distance of but a few miles from the shore. This influence becomes particularly noticeable where the lake shore plains are backed by an escarpment, which serves to keep the lake influence partly confined within a narrow space. This is shown very well indeed near Lewiston at the base of the Niagara escarpment, and also along the Erie shore in Chautauqua County.[1] In both of these places the climates are so favorable that they are the sites of extensive fruit raising.

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[1] See Tarr, Bulletin 109, Cornell University Agricultural Experiment Station, "Geological History of Chautauqua County," Ithaca, N. Y., Jan., 1896; also for other parts of the Lake shores, Winchell, Proc. Amer. Assoc. Adv. Sci. XIX, 1870, 106–117; Kirtland, Amer. Journ. Sci. XIII, 1852, 215–219; Hazen, Bull. 10, U. S. Weather Bureau, 1893. The last three are not for New York, but illustrate lake effects in other States.

In the Chautauqua region the effects of the lake are wonderfully clear. Upon ascending the escarpment the temperature becomes noticeably lower in a distance of a few miles. Very often rain falls upon the lake shore plains while snow is being precipitated on the hills; and during the winter there is frequently sleighing on the hilltops, while no snow exists on the lower plains a mile or two distant. With this difference in elevation there is also a difference in the *amount* of precipitation, and the rainfall upon the hills is perceptibly greater than that on the plains.

There is also a perceptible effect upon the climate in the neighborhood of the smaller lakes. This is illustrated in the valleys of the several larger Finger Lakes which occupy deep trenches in the plateau. In these valleys the winds are deflected somewhat, so that nearly north or south directions of wind are the common ones. Also the valley sides are warmer than the enclosing highlands, partly because they *are* enclosed, but partly because of the influence of the water. Even the small body of water in the lakes serves to modify the neighboring climate very perceptibly. Near the lake shores, both the nights and days of summer are cooler than they are upon the neighboring hillsides, and the winter climate is perceptibly less severe. Here also the marked modification of the climate has given rise to important fruit-raising industries.

In the Mohawk and Hudson River valleys there is the same kind of influence upon the climate, and we find that the isotherms are very decidedly bent in crossing these valleys. Here also some winds are deflected, in the Mohawk to a general east and west direction, and in the Hudson to north and south directions. From this brief statement it is clear that the relation between the physiographic features of the State and the details of climate is very intimate.[1]

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[1] See Chapter XI.

CHAPTER II

THE MOUNTAINS OF THE STATE

Use of the Term Mountain.—There are few geographical terms used more confusedly than that of mountain. In common usage is meant any unusual elevation rising above the surface of the surrounding country. Hence in Texas a hill reaching an elevation of one or two hundred feet above the monotonous plain is called a mountain, while in New England, elevations of even one or two thousand feet are called hills.

In reality more than one geographic feature is included under the single term. If we look at the typical mountains of the world, we find the main fundamental features to be disturbance of the rocks. A part of the crust has been bent or broken; with the result of an unusual elevation. Such mountains occur in ranges, the axes of the folds being longer than the cross section. However, the mountain folds of the land are no sooner begun than they are modified by denudation. The various forms of rock texture are etched, so that very soon the fold is no longer the prominent feature, but instead, peaks or ridges, which have been brought out into relief. In the course of time denudation may so plane down the mountains, that, although the rock structure is that of the mountain, the topography is that of a series of low hills, or in some cases even of a plain. This is the case in the eastern part of Pennsylvania and New York.

In a structural sense, and hence in geographic usage, these planed-down mountain ranges must be called mountains still, although they no longer possess the features which we commonly associate with these geographic forms. In their origin, the topographic mountains are elevated structures of folded or faulted strata; but they are greatly modified by denudation. They are carved into peaks and ridges where harder rocks occur, whether these be horizontal or tilted sedimentary strata, or even perfectly massive igneous rocks.

In such peaks the fundamentally important feature is no longer folding, but rock texture as carved by denudation. So the peak and mountain range are not the same, either in origin or structure. The peak is really a hill, and it may be of great or slight elevation. There can be no real line of distinction drawn between the low Pilot Knob of Missouri, which rises to only a slight elevation above the plain, and the great Pike's Peak; both are carved peaks of igneous rock. Nor is there any essential difference between the low, flat-topped hills or buttes of the plains and plateaus, rising above the general level because of the hard upper strata, and the peak carved out of the equally horizontal and variable rock strata, which exist in the centre of a syncline or an anticline. So it may be held, that in geographic nomenclature we must distinguish between the *mountain peak*, or *ridge*, erosional forms, and the *mountain range*, a structural type, modified more or less extensively by denudation, and perhaps even cut into peaks, though more commonly into ridges. The mountain *range* corresponds more closely with the *geographic* use of the term mountain, while the *peak* is more in harmony with the *common* usage. A geographic mountain need not have an unusual elevation, but *must* have complexity of rock structure; the peak, on the other hand, *must* have elevation, but not of necessity complex internal structure.

Where exactly to draw the line between the geographic mountain and the plateau, and where between the hill and peak, is difficult to define. Concerning the latter, however, there is little real difficulty, for the peak and hill are of the same geographic type; but the mountain and plateau are quite different topographic forms. We are constantly confronted by the difficulty of deciding which is the true mountain, and which so-called mountain is only an elevated and dissected plateau. In fact, the Catskill Mountains of New York furnish a typical example of this difficulty. These are not true mountains in the geographic sense, but are dissected plateaus simulating mountains; they belong to the type which brings confusion to the geographic nomenclature, for nearly every one recognizes them as mountains. They are more than mere peaks, being in reality a group of peaks. The Catskill type of greatly carved horizontal rocks may be called *pseudo-mountains*.

MOUNTAIN GROUPS IN NEW YORK.—There are five mountainous areas in the State of New York. These are the Adirondacks, the Taconic series, extending from Vermont across New York into New Jersey, the Kittatinny Mountains, entering the State from New Jersey, the Palisade range, also entering from New Jersey, and the Catskill Mountains. Of these, three are merely minor portions of mountain masses really belonging to other States. The Adirondacks and Catskills reach the greatest elevation, and from that standpoint are the most representative mountains in New York; and they also are entirely included within its boundaries. Since the Catskills consist of nearly horizontal strata, while the other systems are made of rocks usually complexly folded, the Catskills are really the least representative mountains in the State; in in fact, as has been said before, they are not properly mountains, but imitation mountains.

The Adirondacks.[1]—These mountains furnish one of the most typical illustrations of a class; they are true mountains in form and structure, long subjected to denudation, and reduced to a fraction of their former elevation. Their life history has been long and complex. Commencing at some period of Archean time, long before the beginning of the known geological record, which properly commences with the Paleozoic, they have maintained a land condition almost, if not quite, down to the

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[1] See references, p. 13.

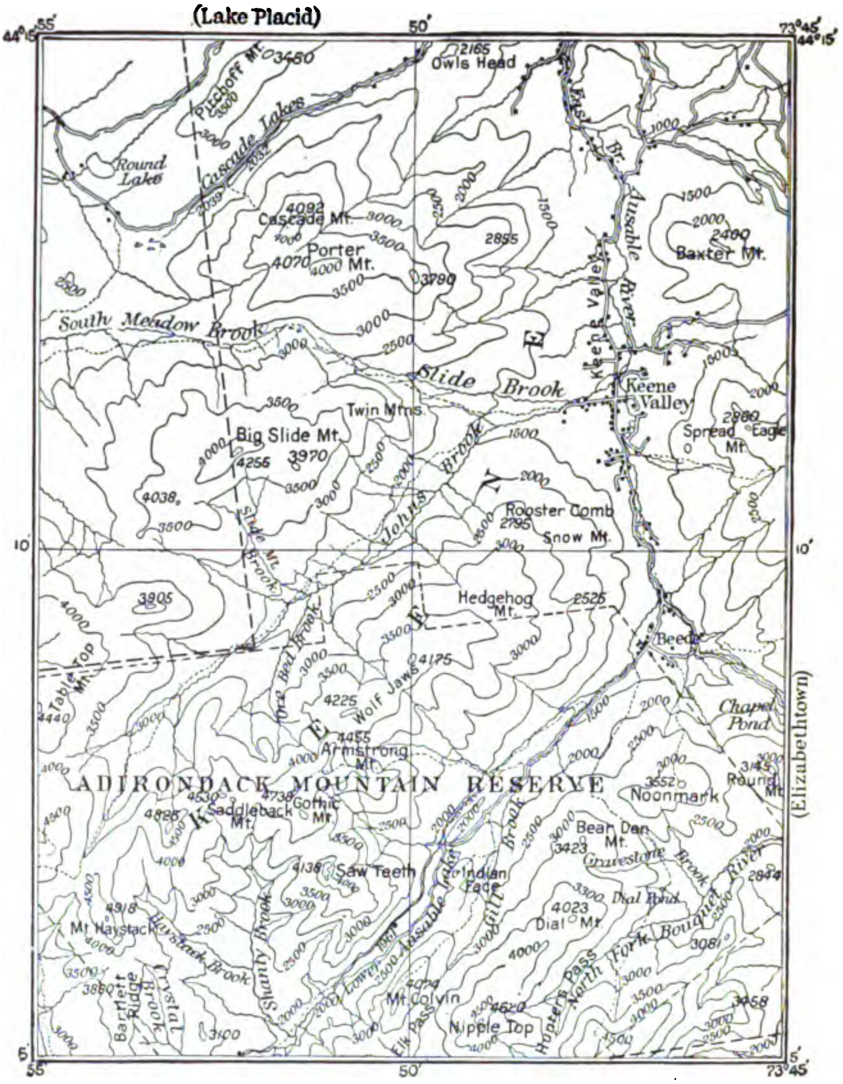

FIG. 6. **Map of a part of the Adirondacks, contours every 500 feet (based on U. S. Geological Survey Topographic Map).**

present time. Their origin and history have been similar to that of the New England and Canadian mountainous provinces.

First elevated during that earliest geological period, the Archean, the Adirondacks rose as an insular land area in the early Paleozoic sea. Then, as now, they were a land of complex structure, composed of hard and durable norities, gabbros, gneisses, etc. Among these were beds of iron and other minerals and rocks characteristic of the crystalline series. The rocks rose into the air and decayed, as rocks do now. Then, as now, rivers flowed down the mountain sides and entered the Paleozoic sea, a part of which occupied the site of the present State of New York, and into this sea the rivers carried sediment derived from the mountains. The waves and currents worked the sediment over, building the strata that now underlie the soil of New York.

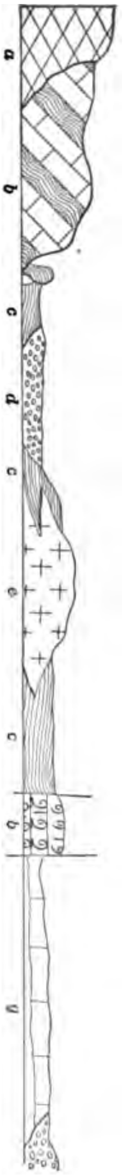

FIG. 7. Section through eastern base of Adirondacks, Essex County, New York (Kemp, 47th Report New York State Museum, 1894).

This history of mountain destruction and sediment accumulation is told us by the beds of Paleozoic strata which encircle the mountains. There are Cambrian beaches built by the waves of this ancient period, and in these the pebbles are of the same rocks as those now constituting the Adirondacks. From this we conclude that when these beaches were accumulated, the mountain rocks were of the same kinds as those now existing in them. In some places beneath these beaches a soil has been found that was formed before the beach gravels were accumulated. This tells us of rock disintegration at some period before the Cambrian sea encroached upon the land. The surrounding strata tell us of another stage in the development of the ancient mountainous area. The Cambrian and Lower Silurian (or Ordovician) strata which surround the mountains are folded and sometimes altered into schists and other kinds of metamorphic rock. From this we learn that after these were deposited in the Paleozoic sea, in a nearly horizontal position, they were uplifted and folded, and with them at least portions of the Adirondacks, of which in some places they now constitute a part (see Figs. 4 and 5).

There is negative evidence, and hence evidence of less value, that this was the last time during which the Adirondacks were extensively folded. South of the mountains stretches an extensive area of Silurian and Devonian strata, in a nearly horizontal position. Therefore, since the beginning of the Upper Silurian these rocks have not been folded; and, since this is true, it seems fairly certain that the neighboring Adirondacks have likewise been free from extensive post-Ordovician folding. On the other hand, however, there is evidence that, though little or no folding has taken place, the mountains have been subjected to uplift; for the beds that were accumulated beneath the surface of the Paleozoic ocean are now raised well above the sea-level. Such an uplift, so near them, must also have been accompanied by an additional elevation of the Adirondack Mountains, although, as has been said, there is no evidence that there was folding accompanying this elevation.

While these changes of elevation were in progress, there were doubtless also times when the level of the land was lowered. In fact this must have been so, for the thickness of the strata between Lower Cambrian and Upper Devonian, in the region south of the Adirondacks, is several thousand feet. These beds, one deposited upon another, were for the most part accumulated in a shallow sea. The evidence of this is that the strata, which vary in texture from pebbles to clay, are mainly made of fragments of rock that have been derived from the land. Such coarse materials could not have been carried far from shore. Moreover, the presence of ripple marks in many of the beds proves shallowness, and beaches that occur among these ancient sediments point to the same conclusion. To form such a thickness of rock in a shallow sea, almost if not quite surrounding the mountains, the bed of the ocean must have been sinking, and if this were true of the sea bottom, a part, if not all, of the Adirondacks must also have been settling. In later times, when the Tertiary sea entered the Lake Champlain valley, there was another period of depression.[1]

During these elevations, foldings and depressions, the Adirondack land mass has been subjected to denudation, for it has stood above the sea-level throughout the greater part of the time that has elapsed since the Archean. Naturally, in so vast a period of time the mountains have been deeply breached; and had it not been for new elevations, we may be certain that, by this time, the area would have been leveled to the condition of a plain, standing near the level of the sea. It is impossible to say how much has been removed from the Adirondacks by this action, but certainly many thousands of feet of strata have been cut off and carried away. Could we know in detail the Archean history of the mountains, we might be able to state how much elevation they have lost by denudation; but while figures cannot be assigned, there is on every hand evidence of immense loss by denudation.

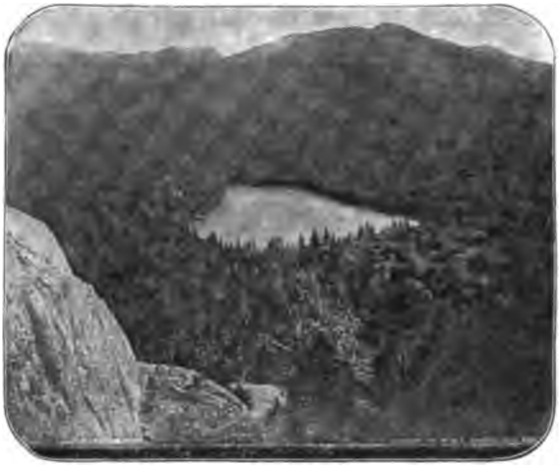

FIG. 8.—The rounded, mature peaks of the Adirondacks (photograph copyrighted, 1888, by S. R. Stoddard, Glens Falls, N. Y).

Examining the surface features of the Adirondacks, we find them to be mountains of considerable elevation, somewhat rugged in outline. Still, when we compare them with the Andes, Alps, or Rockies, we find them to be much less elevated and rugged. There are few lofty, inaccessible cliffs, but instead, rounded, easily scaled hills and mountain peaks, reaching only very rarely to a height greater than one mile above sea-level. Roads may be constructed upon most of the mountain sides, and railways enter the very heart of the system of peaks, while paths are present nearly everywhere, so that practically no portion is inaccessible. This is very distinctly in contrast with the conditions among the Alps, many portions of which are reached only by the most arduous climbing, while some parts are practically inaccessible.

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[1] Marine beaches north of the Adirondacks furnish evidence of lowering and elevation just preceding the present era.

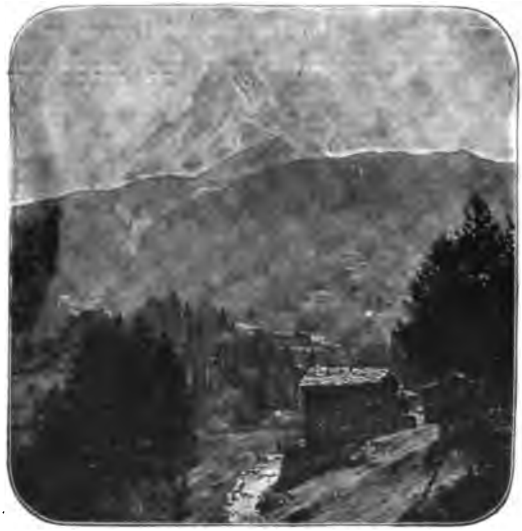

FIG. 9. The Matterhorn, Switzerland, a young mountain peak.

The Alps are *young mountains*, and denudation has progressed only far enough to sculpture the strata of varying hardness into very rugged relief. In the Alps the hard rock masses rise into a Jungfrau or Matterhorn (Fig. 9), peaks of marvelous ruggedness; but in the Adirondacks the long-continued action of denudation has carried the development of the topography from this youthful stage to that of *maturity* or early old age. Here the granitic crystallines stand above the general level as a Mt. Marcy or a Whiteface, while the softer beds are the sites of valleys. But these granite peaks have a gentler and more flowing outline (Fig. 8), because denudation has passed the stage of greatest activity. The height of the mountains has been so reduced that denudation cannot be compared in intensity with that which is possible in more lofty ranges, like those of the Alps.

This rounded form of the Adirondacks has, without doubt, been slightly increased by the scouring action of the ice of the Glacial period, which overrode the highest peaks of these mountains. Too little study has been given to this region for us to state much about the action of the ice there. Some material was removed from the mountain sides and valley bottoms, and some was deposited; and as a result of this modification, the surface was left a little smoother than before the ice came. But we may be certain that this was in the manner of finishing touches, not of primary carving and sculpturing.

In New England, New Jersey, and elsewhere in the East, there is evidence (see p. 100) that denudation succeeded in reducing the mountainous land to even less rugged outline than is now present, and many believe that this reduction amounted even to planation, so that the surface became nearly level, or was reduced to the condition of a *peneplain.* The evidence of this reduction to such moderate outline that mountains lost their mountain ruggedness, is very strong indeed, and the leveling seems to have been widespread. This being so, it must have reached the neighboring Adirondacks. So the Adirondacks are mountains of a new cycle. After a complex history, some of which has been stated, they were reduced to far less relief than now and perhaps nearly leveled. This was in the Tertiary period. Then they, together with the surrounding country, were uplifted again, and once more brought under the influence of mountain denudation. At present they are well along in development in this new cycle, having again reached the outline of maturity. Perhaps such changes have been passed through again and again during the history of these mountains.

The Adirondacks have been contrasted with the Alps; they may also be brought into contrast with the Appalachians, which, likewise, are not strictly comparable with

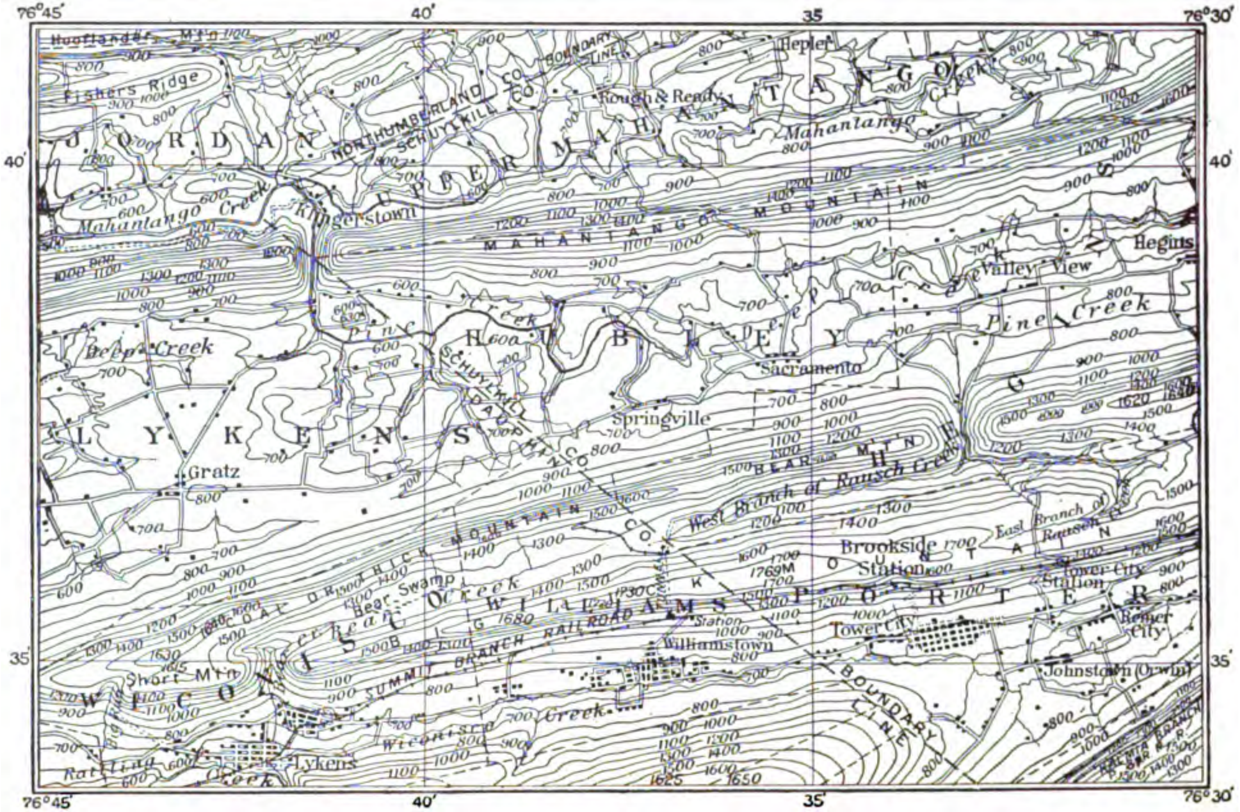

Fig. 10. Map of a part of Appalachian mountains, Pennsylvania. Contours every 100 feet (based on United States Geological Survey Topographic map).

the Alps or Rockies. It is not difficult to ascend to the top of any ridge in the Appalachians, so that in this respect there is a resemblance to the Adirondacks; but if we examine these two sets of rounded and easily traversed mountains, we see some fundamental differences. The Appalachians are made up typically of *ridges* (page 59), while the Adirondacks are typically isolated peaks or groups of peaks. These differences are directly traceable to the rock structure. Denudation employs delicate tools in the sculpturing of the earth, and in the course of its work it detects differences in rock hardness with wonderful precision. The weak or "soft" layers have suffered greatly, while the durable or "hard" rocks have better withstood the action of the tools. Consequently hard strata are etched out in relief as the soft ones are cut more deeply.

The Appalachian rocks are sheets of sediment, variable in hardness and folded into waves, as we might fold the pages of this book. Hence, in etching such layers, denudation carves ridges. This can be understood by bending a series of sheets of card-board, then cutting them horizontally and imagining some to be softer than others. The soft layers, attacked by denudation, are lower in position than the harder ones, and these differences in texture are expressed in ridges and valleys. The hard strata of the Appalachians have resisted denudation and are now elevated. Their edges extend for great distances with relatively narrow width, and the resulting typical form is therefore the ridge (Figs. 10, 11, 12, 17 and 18).

Among the Adirondacks, on the other hand, the rocks have no such sedimentary structure, but are masses of crystalline rock, intimately and complexly associated. Hence the harder portions that are etched into relief have no such linear arrangement, but are in the form of peaks or groups of hills (Figs. 8 and 108). The Appalachian type of mountain might be called the *sedimentary type*, the Adirondacks the *crystalline type*.[1] We will speak of those mountains having the ridge form as the *Appalachian type*, because so typically represented in these mountains; and the crystalline type of peaks may be called the *Adirondack type*.

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[1] Some mountains of crystalline rocks, such as those of New England, have the linear or ridge form of topography, and some massive sedimentary rocks have been carved into peaks resembling the crystalline type.

Having *contrasted* the Adirondacks with other well-known systems of mountains, it remains to *compare* them with their analogues. Their type structure is that of crystalline mountains of rounded, mature form, with peaks caused by the etching out of harder areas of crystalline rocks. The White Mountains of New Hampshire are of the same type exactly; so also are many of the mountains of the Labrador peninsula and the Canadian Highlands; and the same type is found in the Scottish Highlands and the Scandinavian peninsula. In New England there are many others besides the White Mountains which belong to the Adirondack type. Mount Katahdin, in Maine, the Blue Hills near Boston, and many other peaks and

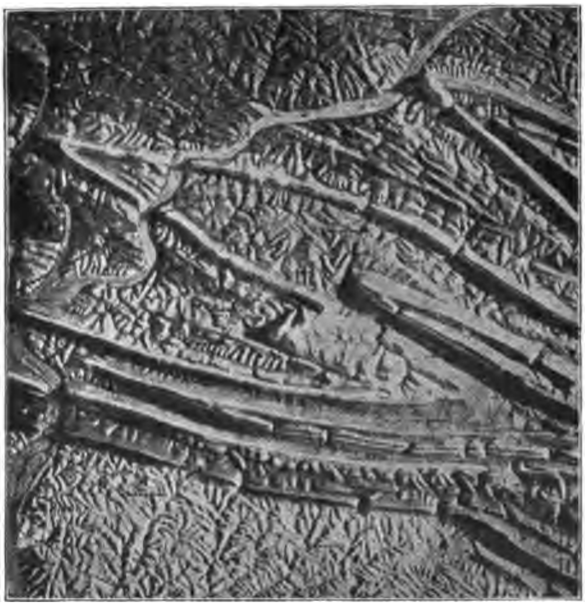

FIG. 11. The Appalachian ridges (a part of Harden's model of the Anthracite coal region, Pennsylvania).

groups of peaks in that part of the country are of this type.

But we cannot properly compare the Adirondacks with *all* the New England mountains, for in many parts of these States, as well as in New Jersey, eastern Pennsylvania, and the more southern States of the coast, east of the Appalachian ranges, there are mountains of mature form, composed of crystalline rocks, which differ from the Adirondacks, first in being generally less elevated and less diversified, and secondly in frequently assuming the form of ridges. These ridges are less distinct than those in the Appalachians, which are made of sedimentary strata, and they are often so dissected that they approach the Adirondack type. In reality they belong to an intermediate group of mountain form, in which the characteristic feature is that of elongated peaks or shortened ridges (Figs. 13 and 15). The mountains of this type may be called the *Berkshire type*, because they are well illustrated in the mountains which were formed during the growth of the Taconic and other ranges in eastern New York and

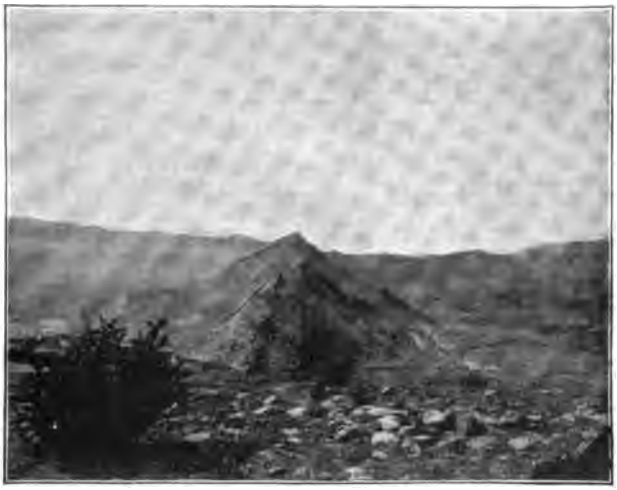

FIG. 12. A mountain ridge of Appalachian type in Colorado. (United States Geographical Survey Photograph.)

western New England. They are most perfectly illustrated in the Berkshire Hills; hence the proposed name.

The Taconic Mountains.[1]—Before the dawn of the Paleozoic time mountains existed in New England and New Jersey, as well as in the more southern States. The sea which bathed the Adirondacks also beat against the foot of these more eastern mountains. This shore line passed somewhere near the New York State border. Remains of these mountains are still left in various parts of New England, where they form mountains of true Adirondack type. By their long-continued denudation, sedimentary deposits were furnished to the interior sea; and during the Cambrian and Lower Silurian periods the waste of this mountainous land, and of the Adirondacks, was strewn over the sea bottom, partly within the boundaries of the State of New York. Similar mountains also occupied the site of the greater part of New Jersey, and the old Archean land probably extended to the eastward of the present shore.

The close of the Lower Silurian was marked by a regrowth of these eastern mountains; but the new rock-folding involved a part of the old sea bed, and, as has been stated, at the same time caused a new development of mighty mountain ranges in western New England (and probably also in eastern New England) and eastern New York. Folds of great complexity (Fig. 14), and faults of marked extent, raised the ocean sediments into lofty mountains, while denudation in time breached these into rugged peaks and ridges. Accompanying this, in many parts of the East, volcanic energy broke forth, and great sheets of lava flowed out over the surface, while beds of volcanic ash were strewn over land and sea.

As in the case of the Adirondacks, the later history of these mountains has been mainly one of destruction in the air. There has been later folding and elevation, as well as depression; but the great post-Ordovician work has

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[1] See references, p. 4.

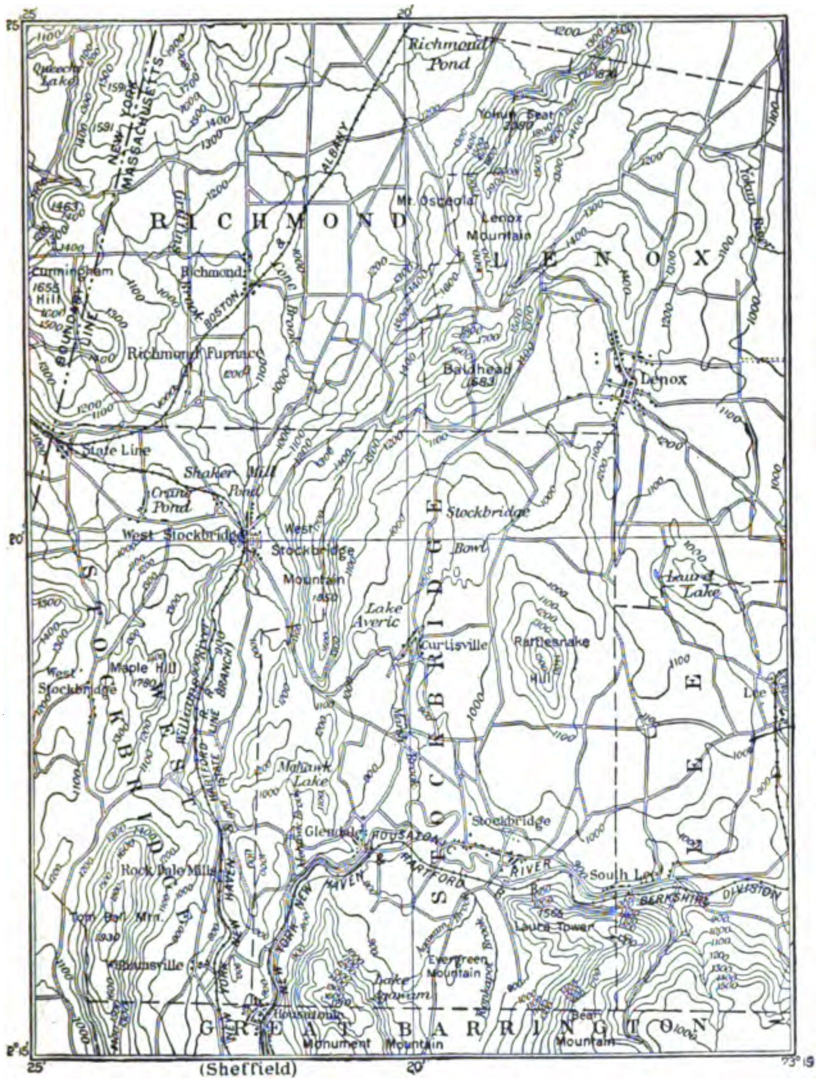

FIG. 13. Map of part of Berkshire hills, western Massachusetts. Contours every 100 feet (based on United States Geological Survey Topographic Map).

been reduction of the mountain height; denudation has so breached the ridges that now their very foundations are revealed, and their internal anatomy exposed to view.

By the study of the basal parts of these mountains, it is seen that the mountain growth was more extensive in the northern than in the southern part, and that it also increased in intensity from west to east. This is proved by the fact that the rocks of the Green Mountains of Vermont have been much more metamorphosed than those in the same line of folding in New Jersey, and that the strata in the Berkshires of Massachusetts have been more highly altered than those of the Taconic Mountains just west of the Berkshires. In some places this metamorphism has proceeded so far that gneisses have been made out of conglomerate, and other sedimentary beds; and nearly everywhere in the New York-New England area the sedimentary strata have been transformed to schists, or the sandstone to quartzite, the limestone to marble, and the shale to slate.

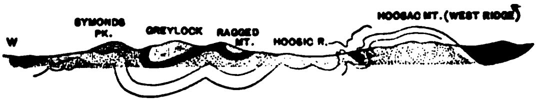

FIG. 14. Cross section of part of Berkshire Hills in western Massachusetts (Pumpelly, etc., Monograph XXIII, United States Geological Survey).

Denudation has etched these complexly altered and folded strata, and since they were originally deposited as *sheets* of sediment, though now greatly changed, the folding has placed them in such a position that, like the Appalachians, they have been carved into ridges. But the *complexity* of the rock structure and position is greater than in the Appalachians, and hence the ridges are not long and continuous, but short and choppy, with many intermediate peaks (Figs. 10 and 15). This is the typical Berkshire type (p. 51). There is a mixture of the sedimentary and the crystalline

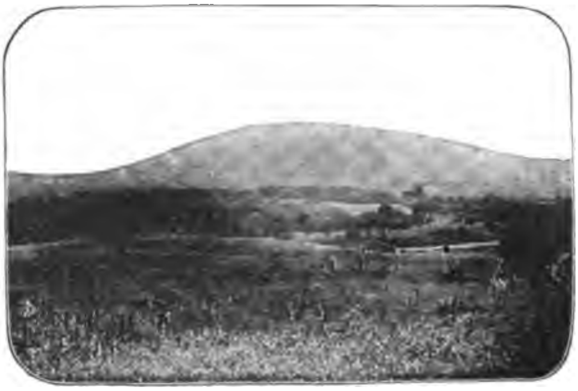

FIG. 15. A short ridge showing the Berkshire type, western Massachusetts.

habits. Thus, in general, the mountains extend in ridges that run parallel to the lines of folding (usually about north and south in New England and New Jersey); but the ridges cannot be followed for a great distance. The difference between the Appalachian and Berkshire types of mountains is quite like the difference between the well-developed ocean swell and the deep, wind-broken waves of the billowy sea.

The Taconic series includes mountains of varying height, some nearly as lofty and rugged as the Adirondacks. These are well illustrated in the Hoosac Mountains of western Massachusetts and the Green Mountains of Vermont. In other parts the ridges are low hills, like those in the southern part of Connecticut and in the neighborhood of New York City. These latter, though in the form of low, well-rounded hills, are as typical mountains, in a geographic sense, as are the peaks and ridges of the Green Mountains. The difference is merely that, in the vicissitudes of denudation, the former have been lowered nearly to a lowland condition. They are mountains reduced in elevation nearly to sea-level. If the rocks that once covered the site of the city of New York could be restored, they would doubtless rise into peaks rivaling the lofty mountains of the world.

Standing upon the crests of the hills in the Highland Mountains of New Jersey, or the hilly land of Connecticut or central Massachusetts, we see that the peaks and ridges rise to a moderately uniform elevation (Fig. 16). Descending into the valleys, the mountains are seen to rise hundreds, and in some cases a thousand or more feet above the valley bottoms. The appearance made by the regular crests, viewed from the hill tops, is that of an undulating plateau; but in the valley bottoms one appears to be in a mountainous region of geographically mature form. This evenness of elevation is all the more remarkable because of the irregularity of the rock structure and position; it looks as if the crests were merely remnants of a former lowland, now elevated and dissected. This supposed lowland has been called a *peneplain*,[1] and the most forceful proof of this former nearly level condition is found in the fact that in a country of moderate ruggedness, and of complex rock structure, the peaks should rise to a nearly uniform level (Fig. 16).

If the evidence of the level crests is to be believed, then the mountains of the East were once reduced to the much lower and more uniform condition of late maturity or even extreme old age. The surface of all the land south of New England and New York was then a lowland. Elevation afterward lifted the beveled mountains and permitted denudation to begin upon a new cycle of work. It has now produced the present low, rounded form, indicating maturity of development in a new cycle. By this explanation of the mountain features, it is necessary to suppose that the ancient peneplain has been lifted higher in northern and western New England than nearer the sea coast. As a result of this greater uplift the high mountains of the north and west of the area are now carved into more rugged appearance than the coastal region.[2]

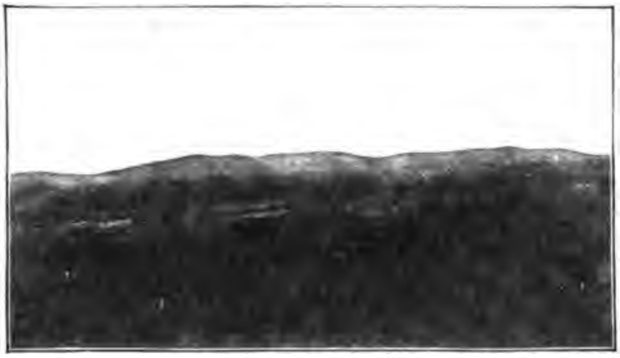

FIG. 16. The ancient mountains of New England, showing peneplain surface.

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[1] Davis, Amer. Journ. Sci., Ser. III, XXXVII, 1889, 430; Proc. Boston Soc. Nat. Hist., XXIV, 1889, 373; Nat. Geog. Mag., II, 1895, 81; National Geographic Monographs, I, 269; Bull. Geol. Soc. Amer., VII, 1896, 377; Tarr, Amer. Geol., XXI, 1898, 351; Davis, Amer. Geol.; XXIII, 1899, 207.

[2] It should be stated that I am not convinced of the full truth of this explanation, but believe that it should be modified (p. 100).

Other mountainous areas which are believed to have once reached the old age condition of the peneplain, and later to have been lifted, are described from various parts of the earth. Besides the New England case other peneplains have been described in New Jersey and the crystalline region east of the Appalachians, as far south as Alabama. In Europe, cases are reported from the valley of the Rhine, the Scandinavian peninsula, the Highlands of Scotland, etc. From the numerous instances, it would seem that in the Tertiary period there was a widespread leveling of the land, which indicates that over large areas there was a general freedom from extensive elevation. It would also seem that this period of land quiet and land lowering was succeeded by a time of general uplift and deep dissection.

The Berkshire type of mountain, especially well illustrated in western Massachusetts and eastern New York, is also found all the way along the eastern base of the Appalachians, as far as Alabama. Undoubtedly its counterpart will be found in various parts of the earth, in portions of all the great areas of low mountains composed of crystalline rock. The type may be looked for in New England, Labrador, Greenland, Scandinavia and Scotland; and in many places it may grade into, or be intimately associated with, the Adirondack type of mountain structure on the one hand and the Appalachian type on the other.

The Kittatinny Mountains.[1] — The folds of the Appalachians involved only a small part of southeastern New York. The broad plateau of the State was raised and the rocks composing it were slightly folded; but in one part, in Orange, Sullivan and Ulster counties, ridges of distinct kind enter the State from New Jersey. These, given various names, are the continuation of the Kittatinny range of New Jersey.

After the Taconic Mountains and the ranges of New

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[1] See Mather, Geology of New York, 1st District, 1843, 355–7; Darton, Nat. Geog. Mag., VI, 1894, 23–34; New York State Museum, Report 47, 1894, 485–566.

England were elevated, near the close of the Ordovician time, the sea occupied the greater part of New York State, and continued to do so until the beginning or middle of the Carboniferous period. The Taconic Mountains, and those of the New Jersey Highlands, formed the eastern boundary of this sea, and at that time the site of the Appalachians was sea-bottom near the eastern shore line. Then, near the close of the Carboniferous time, there came an uplift, involving the New England region, and extending at least as far south as Alabama. Sedimentary strata were folded into ridges, sometimes with rock folds and faults of great complexity, but generally in simple or slightly overturned anticlines and synclines. In the greater part of the area outside of New England, the folding was not sufficiently intense to greatly metamorphose the strata, which therefore still exist as sedimentary layers of conglomerate, sandstone, shale, limestone, etc. (Figs. 17, 18, 25 and 26).

These Appalachian foldings probably affected the entire southeastern part of the State of New York; but the influence upon the ancient mountains, which were uplifted in Ordovician times, is so masked that it is difficult to detect. It is in Pennsylvania that the Appalachian ridges are most typically developed (Figs. 10 and 11), and some of these enter New Jersey and cross into New York. Of these the most notable are the Kittatinny Mountains, which, at the New Jersey-Pennsylvania line, are traversed by the Delaware River, where it passes through its famous "Gap." Folded rocks here stand tilted at a high angle with the strike extending in a northeast direction. These mountain ridges are capped by a hard layer of conglomerate, and rise to a wonderfully uniform level.

This range grades westward into less and less folded strata, and finally the folds give place to nearly undisturbed horizontal layers (Fig. 26), just as they do in Pennsylvania west of the Appalachian chain. In New York the folds also die out toward the north. Hence, pronounced in New Jersey, the ridges become less notable in New

York, and finally practically disappear in Ulster County. There they merge into and give place to an escarpment of Helderberg limestone, forming the so-called Helderberg Mountains of Albany County.

These foldings tilted the horizontal strata and elevated them into mountains; denudation sculptured and lowered them, and, it is believed, even reduced the mountains to a lowland of moderate level, like the peneplain of New England. When, in late Tertiary times, New England and the neighboring regions were elevated, the Appalachians were again raised, not perhaps by folding, but by a slow uplift, which, giving new life to the streams, and new power to the agencies of the weather, permitted the sculpturing of the rocks anew. The softer layers were removed and the harder ones left standing in relatively prominent position. Since the ocks are tilted *layers* or *sheets*, this sculpturing commonly caused ridges where harder strata occurred, and valleys where softer beds existed between them. This is the characteristic Appalachian type of mountains, and it is seen in the Kittatinny Mountains of New Jersey and the Shawangunk Mountains of New York (Fig. 17). Sometimes the durable rock at the crest of the ridge is conglomerate, at other times sandstone, and still again, as in the Shawangunk, a limestone of dense and resistant nature. Upon these ridges one may often travel for miles at a nearly uniform level.

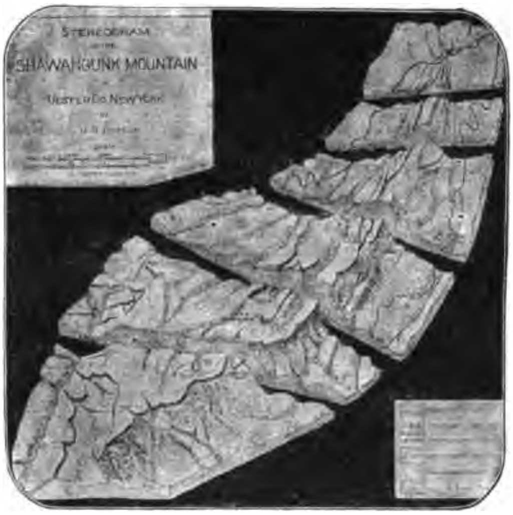

FIG. 17

So the mountain ridges of the Appalachian type in New

York, represent mountains of mature form, without great relief, but with moderate, easily scaled slopes, quite in contrast to Alpine or Andean ruggedness. They have passed the stage of rugged youth, but their maturity of form is that of a new cycle; for formerly they were more reduced, and now they have advanced as far as maturity in a new life history, made possible by elevation.

The stage of mature development is found in many of the mountains of the world. (See page 47.) It is especially well shown in the entire Appalachian chain. The type of mountain form called the Appalachian, whose characteristic feature is the ridge of sedimentary rock, made into a ridge because of the resistant nature of some of the beds, is seen all through the Appalachians (Figs. 10 and 11). The ridges are etched into moderate relief by denudation, and the slope is more gentle on the side toward which the layers dip than on the opposite face (Fig. 19). In the Sierra, the Coast Ranges, Basin Ranges, and Rocky Mountains of the West (Figs. 12 and 19) it is a common type, as it is in the Andes, the Himalayas, the Alps, Jura and a multitude of other mountains of the world. There is much difference, however, in the details of form, due to differences in rock complexity or to age and consequently to degree of development. The typical Appalachians are mature in geographic form. But among many of the younger mountains mentioned above (the Andes, etc.), the time for the action of denudation has not been sufficient to carry the topographic outline far enough for the thorough development of the type features. In origin and rock structure they are of the same type as the Appalachians; but they are not sufficiently mature for the full development of all their latent possibilities. Given time, they will become so, for they are of the same geographic family. But in

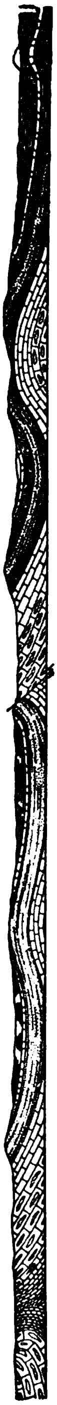

FIG. 18. A section showing Appalachian folds and etched mountain ridges (Hayes, United States Geological Survey, folio 2, Ringgold)

many cases the development of the ridge form cannot attain the perfection found in the Appalachians because the rock structure is far too complex.

The Palisade Ranges.[1]—When a much more durable rock occurs among softer ones, in the course of denudation it will remain well above the general level of the others. It is upon this principle that the ruggedness and many of the characteristic features of mountains depend. In New Jersey there is a series of such dense beds of unusual kind, and one of these enters the State of New York along the western bank of the Hudson, from Upper Bay to Haverstraw. These are beds of trap rock, a black, dense diabase, which is decidedly more durable than the enclosing sandstone strata. In New York the diabase forms the Palisades, in New Jersey several ranges of hills or low mountains, notably those along the Hudson, near Hoboken, and also those near Paterson, Orange and other parts of northeastern New Jersey.

FIG. 19. A mountain ridge in western Canada. (Notman, Photographer).

During the Triassic, eastern New Jersey was beneath the sea. An arm of the ocean also extended up the Connecticut at least as far as the Vermont boundary; and at the same time various other parts of the Eastern States were submerged. Beds of sandstone and shale were deposited in nearly horizontal position in these ocean bays. At the same time, in the Connecticut valley, and perhaps also in New Jersey, volcanoes sent forth flows of basaltic or diabasic lava, which entered the seas and covered the sands and clays, very much in the same way as the basalt of the Hawaiian volcanoes is doing now. These lava sheets were then buried beneath other sandstone beds deposited in the sea.

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[1] See references, p. 2.

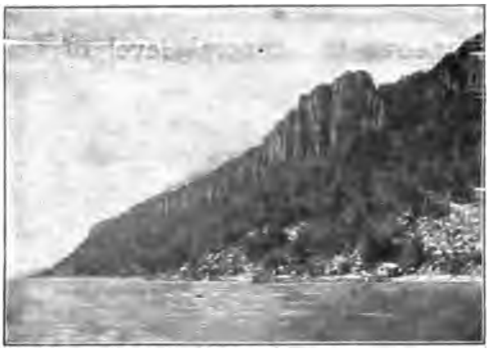

FIG. 20. The Palisades of the Hudson.

Approximately at the same geological time, or possibly a little later, lava rising toward the surface was *forced into* the sandstone, between the layers of which it spread out in extensive sheets. In this way the trap of the Palisades was introduced into the rocks. After this the Triassic beds of sandstone, with their included lava, were elevated above the sea, broken by faults and tilted from the horizontal position, so that there were produced alternate beds of lava and sandstone, inclined at various angles. The forces of denudation have removed much material from this series of rocks, and have etched the harder lavas into relief, so that they now stand up distinctly above the surrounding country.[1] In topographic form they simulate the Appalachian type in the fact that they are usually ridges, though the ridges are less continuous, and also more curving, generally with a diminution in elevation at one end (Fig. 21).

This may be called the *Palisade type* of mountain, because typically illustrated there. Aside from the instances mentioned in New Jersey, this type finds illustration also in the East and West Rocks near New Haven, Connecticut, the Hanging Hills near Meriden, Connecticut,

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[1] Like the other mountains of the East, the crests of these rise to a nearly uniform sky-line, which, as in the other cases, has been interpreted to represent the remnants of the ancient lowered land, or peneplain.

Mounts Tom and Holyoke in Massachusetts, and Cape Blomidon, Nova Scotia. The typical feature is that of a ridge, or a series of ridges, of tilted trap rock, either lava flows or intrusions, etched into relief as are the ridges of harder rocks in other mountains. They differ from the true Appalachian type in the fact that they are monoclinal, and that the ridges are not associated with anticlinal and synclinal folds. Frequently, if not always, the uplift is due to faulting. This is noticeably the case in the Connecticut valley, as has been so clearly shown by Professor Davis.[1] In passing over this interesting phase in the geographic history of the State, it should be stated that the old volcanic centers from which the lavas came, including the cones, if any ever existed, have long since been lowered by denudation. That the volcanic energy was widespread in its effects, is shown by the fact that, from Nova Scotia to Carolina, dikes of this black trap rock cut the strata. The volcanic activity was not manifest far west of the present coast line of New York, but seems to have been most intense approximately along that line. Dikes, possibly of the same age, are found cutting the Devonian shale near Ithaca, N. Y. They abound in the Highlands of New Jersey and of New England and in the Champlain valley and the Adirondacks.

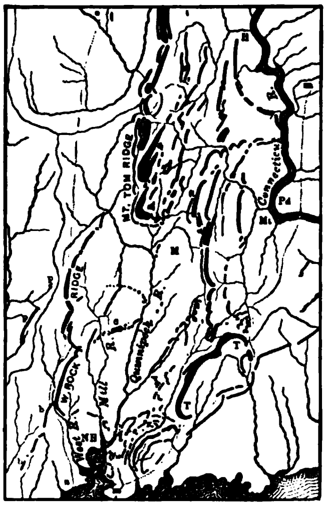

FIG. 21. Trap ridges (black) in Connecticut valley. (Dana's Text Book of Geology, after J. G. Percival.)

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[1] Davis, Seventh Annual Report U. S. Geol. Survey, 1885–6, 455; Davis and Whittle, Bull. Mus. Comp. Zool., XVI, 1889, 99; Davis and Loper, Bull. Geol. Soc. Amer., II, 1891, 415; Davis and Griswold, Bull. Geol. Soc. Amer., V, 1894, 515; Davis Amer. Journ. Sci., Ser. IV, I, 1; Davis, Pop. Sci. Monthly, 1891, 221. See also Percival, Geology of Connecticut, 1842, 299; Dana, Manual of Geology, 4th Ed., 1895, 800; Emerson, Bull. Geol. Soc. Amer., II, 1892, 451.

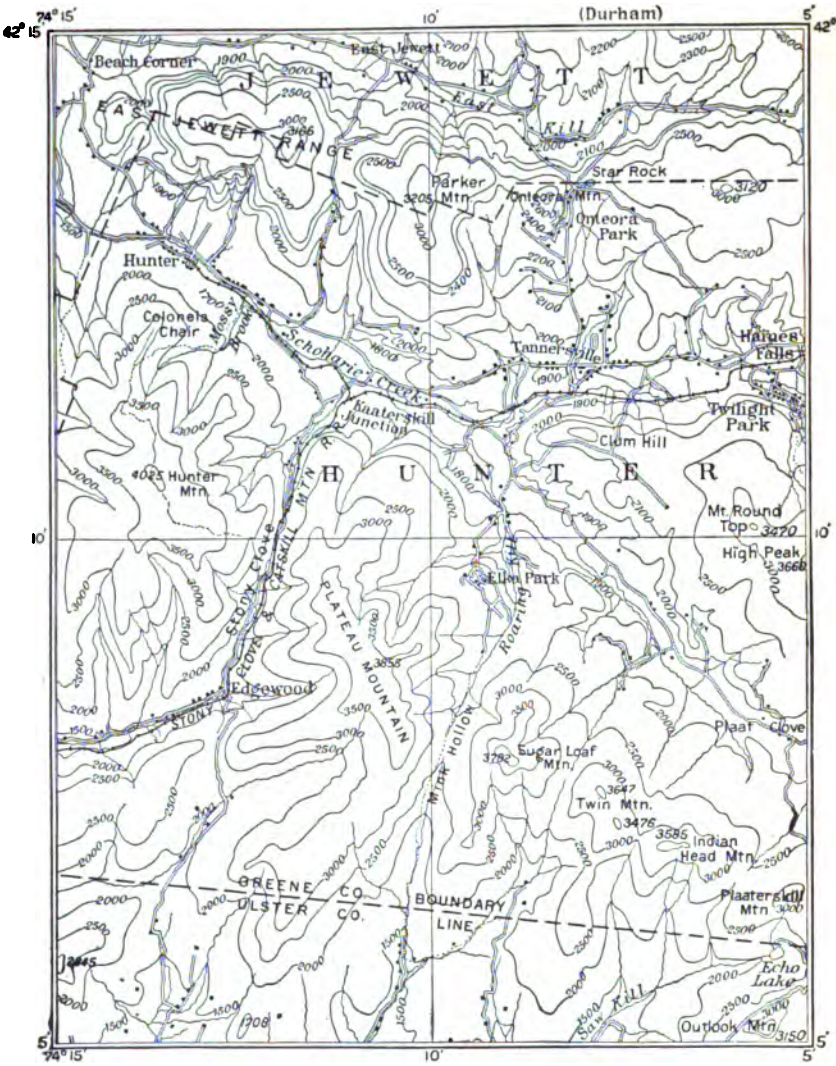

FIG. 22. Map of part of Catskill mountains, contours every 500 feet. (Made from United States Geological Survey Topographic Map.)

The Catskill Mountains.[1]—As was stated on page 41, these are not true mountain ranges but rather pseudo-mountains. During the Devonian period, just before the uplift of the great interior Paleozoic sea which accompanied the development of the Appalachians, the site of the Catskills was the shore line of a sea-bottom that was slowly sinking. The land side of the shore was occupied by the Taconic Mountains, from which sediment entered the sea, where it was strewn over the bottom in the region where the Catskill Mountains now rise. Here, near the coast, coarse beds of sandstone and conglomerate were accumulated, while further west, shales and sandy shales were being deposited. The sinking of the sea-bottom permitted these beds to gather to great depth. Then, when the reverse process of elevation had commenced, the sea-bottom was raised to dry land, and eventually uplifted to the condition of a plateau. Possibly the uplift in the Catskill region was greater than that in central New York, although of this there is no direct proof. But in both places the elevation was accompanied by very little disturbance of the strata, so that in the two parts of the State the upper Paleozoic beds are still nearly horizontal.

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[1] See references, p. 7.

This great New York-Pennsylvania plateau, which borders the western base of the Appalachians, is now considerably dissected. While in most parts it is a fairly level plateau, as viewed from the higher hills, it is, nevertheless, deeply cut by broad valleys. This is true throughout the State; but in the Catskill Mountains the topography is much more rugged and more mountainous than elsewhere. Denudation, operating upon hard rocks of nearly horizontal position, has carved out a complex of peaks (Fig. 22), which, because of the superior hardness of their rocks, rise higher than the rest of the plateau.

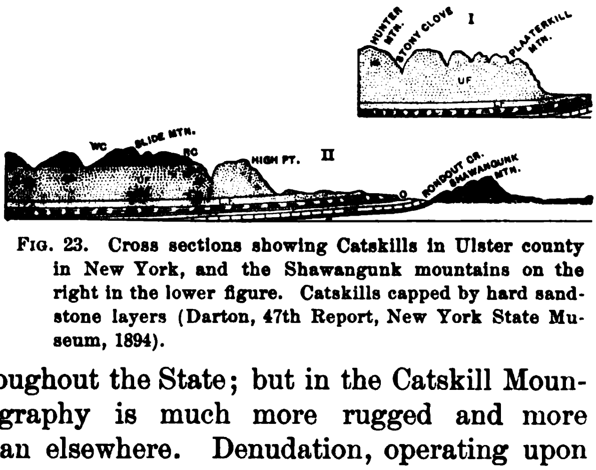

Fig. 23. Cross sections showing Catskills in Ulster county in New York, and the Shawangunk mountains on the right in the lower figure. Catskills capped by hard sandstone layers (Darton, 47th Report, New York State Museum, 1894).

As might be expected from the association of the

Catskills with the Appalachian uplift, the horizontal rocks of the higher and more typical portion of the Catskill region change gradually (Fig. 23), toward the south and east, into a region of disturbed rocks, thus merging into the true Appalachians. In these sections of the State there is every gradation from the plateau feature to the true folded mountain. The counterpart of the Catskills is found in various parts of the mountainous plateau region on the border between the Appalachians and the real plateau which lies west of their base. This is notably the case in the Cumberland plateau in Tennessee. The same features are present in innumerable places in the great plateau region of the Far West.

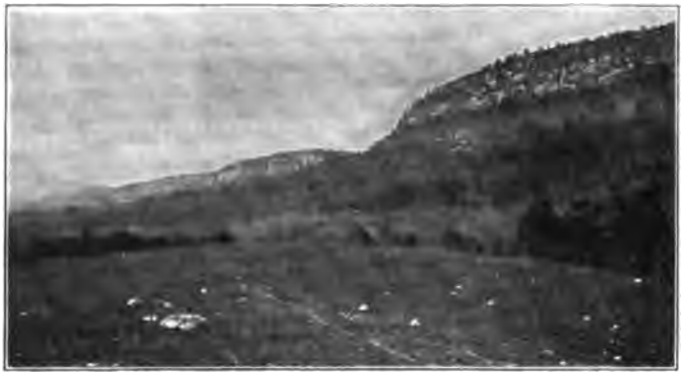

Fig. 24. The Helderberg "mountain" where the durable horizontal Helderberg limestone outcrops, forming a pronounced escarpment, giving rise to the name mountain.

This case of the Catskills is an interesting instance of the simulation of features of one geographic type by another of quite a different kind. The life history of a mountain *range* involves folding and uplift of the rocks into complex topographic features. At first denudation increases the complexity, and brings out the variations in rock texture into markedly rugged contrast. The tilted position of the layers, and other complexities of rock structure, increase this irregularity. Then as denudation continues, the ruggedness decreases, and the surface is made smooth, while the elevation is thereby diminished. This may proceed until old age, when the formerly irregular surface becomes reduced nearly to the condition of a plain.

So also the plateau, with horizontal rocks of varying hardness, commencing as a level surface, is etched by the agencies of denudation, and becomes more and more rugged and mountainous, until finally it so closely simulates the true mountain that in common usage it takes the name of mountain. Then, in this case also, as denudation proceeds, there is first produced a less rugged surface, and finally a plain. In the middle and final stages these two diverse forms resemble each other in surface outline, though so utterly different in internal structure and origin.

The difference between the typical *Catskill type* of mountain and the Alpine ranges of highly folded rock, is striking, when we consider the extremes. But there is no hard and fast line to be drawn between the two. By degrees the folds of the mountains die out toward the border of the plateau and change from tilted to horizontal strata quite imperceptibly (Figs. 23, 25 and 26). Where in this gradational area are we to define the boundary between the mountain and plateau? For instance, is the Lookout Mountain (in the vicinity of Chattanooga, Tennessee), with its nearly horizontal limestone capped by sandstone, a mountain or a plateau? It is a part of a broad syncline, and it is quite flat-topped and elevated because of the greater resistance of the upper sandstone beds. Calling

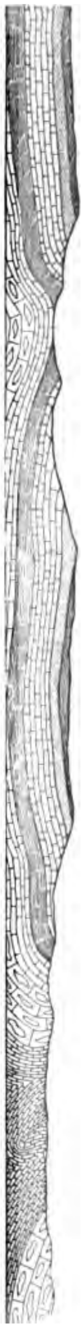

Fig. 25. Cross section, showing change from mountain folds to plateau (on the left), Tennessee (Hayes, United States Geological Survey, Folio 2).

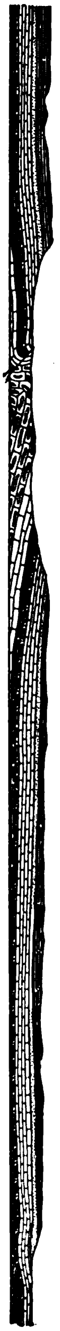

Fig. 26. Cross section, showing plateau form of mountain, Walden Ridge (right half), (Hayes, United States Geological Survey, Folio 6).

this a true mountain, as we apparently must, what of Walden Ridge (Fig. 26), to the west of Lookout? This is still gently folded, but it is a much broader and more typical plateau. Still to the west of this, and west of the Sequachee valley, is the Cumberland Plateau, where the rocks are nearly horizontal, and practically beyond the zone of folding. No doubt this should be called a plateau and Walden Ridge probably a mountain; but wherein lies the essential difference?

Here, as nearly everywhere, the geographer who would classify is confronted by the difficulty that we wish to draw distinctions where none really exist. The *typical* species of animals and plants, or of minerals and rocks, or of geographic forms, are easily separated and defined; but when we examine them further, we find them grading one into the other. Then the definition no longer defines, nor can the distinction longer be followed.

CHAPTER III

PLAINS AND PLATEAUS

DEFINITION.—A plain is a level tract of country, and it is customary to limit the term to level tracts not high above the sea, while those that are elevated are called plateaus. Naturally this distinction has little if any meaning, even in common usage; for there are many so-called plateaus, such as that on the western side of the Appalachians, which are less elevated than the "plains" of the West. Therefore I do not consider it worth the while to attempt to maintain the distinction in this article. Plains and plateaus are of the same genus, the difference arising chiefly out of the difference in elevation and the results which this makes possible.

LIFE HISTORY.[1] — Both plains and plateaus, in their typical form, are notably level areas; but a plain that for any reason begins as a level tract, will, if opportunity offers, become irregular. Upon its surface water will flow; and this, if high enough above sea-level, will of necessity cut channels. Consequently the plain will begin to be dissected, and if it is a plateau high above sea-level, it may be so deeply carved that, like the Catskills (p. 65), it becomes so mountainous that people class it among mountains. Therefore in the development of a plain from an original fairly level condition, greater and greater irregularity is introduced, until the plain becomes a hilly, or, it may be so far as differences in level go, even a mountainous country.

At first[1] the streams cut steep-sided valleys: to shallow depths if the plain is low, but as great canyons if on a high plateau. This is because the streams cut rapidly

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[1] Davis, Proc. Amer. Assoc. Adv. Sci. XXXIII, 1884, 428–32.

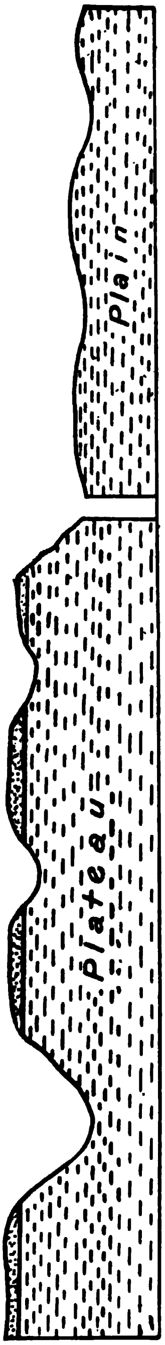

FIG. 27. Diagram to show the type conditions of plain and plateau. Basal line sea level. Crests of hills in plateau capped by hard stratum.

along their channels and carve valleys only slightly wider than themselves. But the weather is at work all the time, and this broadens the valleys, making them less angular. Yet so long as the stream can cut into its bed, *its* action is more marked than that of weathering, and, although the valley broadens, it still remains a gorge or canyon. In time, however, the stream cuts so low that further deepening is either greatly checked or wholly stopped. Weathering, however, continues to broaden the valley which is no longer being deepened, and this carving of the plain in time produces broadly sloping valleys and gently rounded hills. This stage is reached much more quickly in a moist than in a dry climate, because the agents of weathering are more active in the former than in the latter. This is one of the reasons why the plateaus of the arid West are crossed by rugged and narrow canyons, while that near the base of the Appalachians is carved into rounded hills and valleys.

Beyond the stage just mentioned the development is slow; but since the streams can cut no deeper, while weathering is constantly lowering the surface, there is no other end than the ultimate reduction of the surface to a level condition, provided the land stands quietly and nothing occurs excepting this normal work of water and weather. The plain, at first roughened by these causes, becomes more and more smooth, after a certain stage is reached, until in the end it will actually become a plain again, as at the start, though this time with the surface near sea-level. It happens that the land *is* in movement, and that other changes may occur to interrupt this development, so that the full cycle is rarely, if ever, completed. Of *young plains* (A and B—Fig. 28), that is, those newly formed, there are many; of *mature plains* (C—Fig. 28), that is, those considerably dissected, there are also great numbers; but of *old plains* (D—Fig. 28), those that have passed into a second childhood, there are no perfect examples known with the possible exception of some that are buried beneath sedimentary layers. The *rate* of development from youth to old age, as well as the intensity and variety of surface form produced, will vary greatly with the elevation above the sea, the kind of rock, whether hard or soft, the slope of the surface, and the climate.

CLASSIFICATION OF PLAINS.[1]—There are two great classes of plains, those that have resulted from *destruction* of land and those that have been built up, or *constructed*. The former may be called *destructional*, the latter *constructional*. Both classes may be made by several causes, such as the action of the sea, of lakes, of rivers and of glaciers. Plains produced by these causes may be called *Ma-*

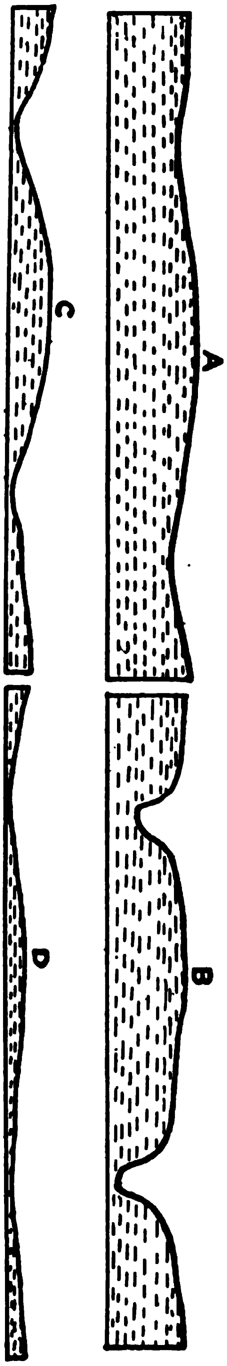

FIG. 28. To illustrate the ideal development of a plain in rocks of uniform texture, starting with an undulating surface in A; trenched by steep-sided valleys in B; these broadened out in C to the condition of maturity; and finally, in D, a gently undulating plain developed through denudation, but this time near sea-level.

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[1] See also Davis, Proc. Amer. Assoc. Adv. Sci. XXXIII, 1884, 428–32; Powell, Nat. Geog. Monog., Vol. I, 1896, 34.

rine, *Lacustrine*, *Fluviatile*, and *Glacial*. When a glacier is ending on the land, its melting furnishes both water and sediment in amounts quite different from that which would come under more normal conditions of water action. The action of this ice-furnished water may *build* plains, as well as carve them, and these may be called *Glacio-fluviatile* plains. Volcanic action, by outpouring lava or volcanic ash, may build *Volcanic* plains. During the general wearing down of the surface, by the action of *denudation*, plains may be formed by the important agents of destruction included in this term. Plains originating from *either* one of these causes may be newly formed, and hence *young*, or they may become *mature*, or, theoretically, any one may have passed to the stage of *old age*. These facts are graphically stated in the following table, to which are added the names of some of the chief subdivisions:

CLASSIFICATION OF PLAINS

	CONSTRUCTIONAL.	DESTRUCTIONAL.	
Marine.	Salt marshes. Deltas. Filled bays. Raised sea-bottoms.	Wave cut plains.	Any of these may be young, mature or old.
Lacustrine.	Fresh water marshes. Deltas. Filled lakes. Lake bottom plains.	Wave cut plains.	
Fluviatile.	Floodplains. Terraces.	River cut plains. Terraces.	
Glacial.	Till plains.	Ice-scoured plains.	
Glacio-Fluviatile.	Gravel-filled valleys. Overwash plains. Terraces. Deltas. Sandplains.	Same as Fluviatile.	
Volcanic.	Lava flows. Ash fields.	None.	
Plains of Denudation.	All of the above excepting volcanic.	Plains in horizontal rocks Peneplains.	

CONSTRUCTIONAL PLAINS

Marine Plains.—Along a very large part of the seacoast line of New York, *salt marshes* are in process of construction, and one finds every gradation, from a bay to an extensive marsh. This coast line, which is mostly that of Long Island, is very irregular, and the indentations have chiefly resulted from a recent sinking of the land, which has allowed the water to enter the valleys. As a result of this sinking the Hudson, and many of the streams of Long Island, enter the sea, not over deltas, but at the head of small bays. These partly protected indentations do not receive the full force of the ocean waves, and hence the sediment that is dragged down from the land by rain-wash and by rivers, is not removed by sea action, but accumulates on the bed of the bays, tending to fill them. To this source of sediment is added that pushed into the bays by the ocean waves and currents. An even more important reason for the protected condition along a large part of the coast of Long Island is the construction of bars of sand by wave and wind action. The greater portion of the south shore of this island is largely shut in by sand bars, or beaches, at some distance from the true land margin, or the *old land.* The *new coast* is therefore straighter than the old, and the space between the old and new land is occupied by protected bays and sounds. From here southwards to the Rio Grande, excepting at the southern end of the Florida peninsula and the delta of the Mississippi, these same conditions exist.

Delta Plains.—Where streams enter these bays they deposit their sediment very nearly at the place where the current is checked upon entering the quiet water. The continual dumping of material here will, in time, build *marine delta plains.* Layer upon layer is deposited, and the delta grows outward into the bay, with a level upper surface and a steep front under the water, upon the face of which sheets of sediment accumulate at a steep angle (Fig. 29). Thus, built as a plain, which is a part of the seashore, it cannot grow far above sea-level. It must be a nearly dead-level plain, and when the stream which is building it, and which extends out over it, is in flood, the nearly horizontal river channel cannot contain *all* the water that is supplied. Therefore the water overflows the delta and deposits upon its surface a horizontal layer of sediment, so that the plain is actually built a slight distance above sea-level, as is the case in the delta of the Mississippi. Being generally enclosed between hill slopes, sediment is washed from the sides. In such cases the delta is a plain sloping from the valley-sides toward the middle, as well as from its head to its margin, which is really some distance under water, where it terminates in a terrace front that is constantly being extended seaward.

FIG. 29. Ideal section of a delta.

Such a delta plain is very level, but yet is marked by some depressions and elevations. Near the stream channel, and elsewhere, where more deposit is made, the surface rises above the general level. Furthermore, the river may enter the sea through two or more mouths, or *distributaries* (Fig. 30). Now and then it abandons one of these, or changes its course, thus leaving the old channel and carving a new one. Then the abandoned channel becomes a *bayou*, and later, cut off from the sea and river by the deposit of sediment, may become a lake. But these are all minor irregularities in a plain of remarkably uniform general level.

Filled Bays.—Fine sediment brought by the rain and the small streams, as well as some of that coming from the large rivers, together with some of wave origin, drifted about by tidal currents, is strewn over the bed of the bay. This is deposited quite irregularly, according to the rate of supply and the velocity of the current, which vary from place to place. If this filling continues long enough, the

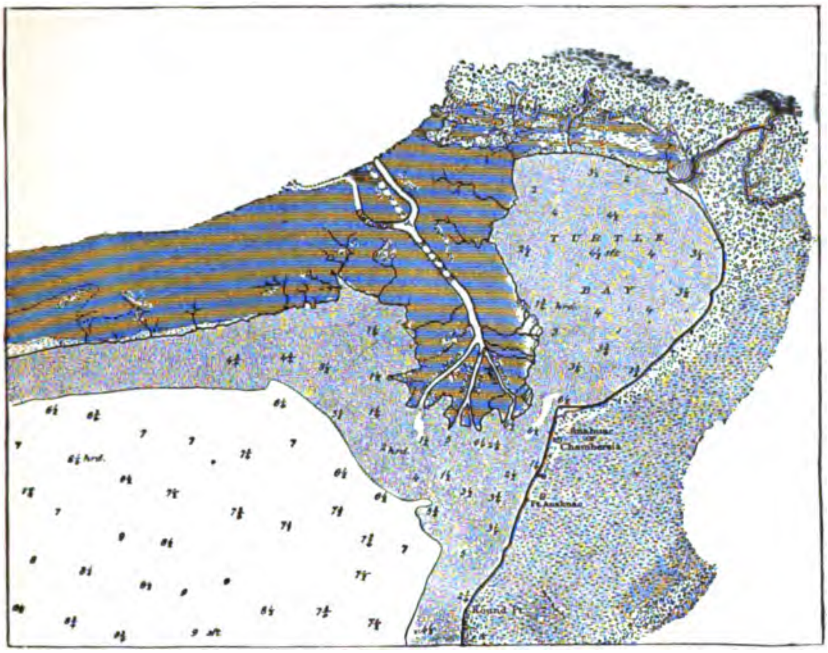

FIG. 30. Map of a delta at the head of Galveston Bay, Texas, where the Trinity river enters. Note the shallowness of the water near the delta and in Turtle Bay (from United States Coast Survey Chart 204).

effect is to transform the bay to a level plain (a *filled bay*), whose elevation is approximately that of the sea-level, at which level further deposit is greatly checked and finally stopped.

Salt Marsh Plains (see also pp. 324–328).—This work of bay-filling is greatly aided by the action of marine plants.[1] When any portion has risen nearly to the low-tide mark, *eel grass* commences to grow, and this, by checking the velocity of the tidal current, adds to the shallowness, which is still further increased by the death of the eel grass itself, as well as by that of the animals which it supports. This continues about to the low-tide level, where the eel grass ceases to be able to thrive. Above this there is a barren zone up to the level of the mid-tide, where other plants, the ***salt marsh*** grasses, commence to thrive, with the same results. Salt marsh plants grow upon a salt swamp up to the level of the highest tide, and as a result, extensive plains are being built by their aid in the enclosed bays; and in some places these salt marshes extend from the ocean beach or bar to the margin of the old land (Fig. 30). They are then remarkably level marine swamps, with minor irregularities, covered at very high tide, but exposed to the air for most of the time. Across them extend many river-like, tidal channels, through which the rising and falling tide passes. In time even these depressions are filled, and gradually

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[1] Shaler, Sixth Annual Rept. U. S. Geol. Survey, 1885, 353–398.

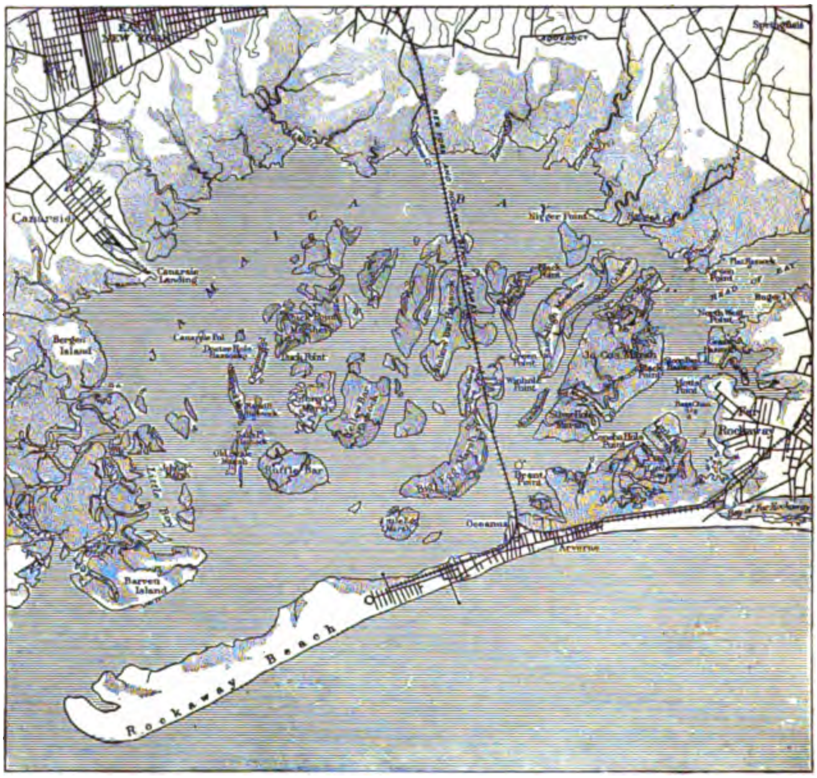

FIG. 31. A nearly filled bay, just south of Brooklyn, almost enclosed behind a bar called Rockaway Beach. Very notable development of salt marsh, represented by the dotted shading (from Brooklyn Sheet, United States Geological Survey).

the plain is raised above the level of the highest water, and the salt marsh then becomes dry land.

These salt marsh plains have considerable economic importance. There are scores of thousands of acres along the seacoast, not far from the large cities, which need only the exclusion of the tide to transform them to arable land. Already in some cases this has been done by artificial diking, and in the Land of Evangeline, on the shores of the Bay of Fundy in Nova Scotia, as well as along the coast of England, and particularly in Holland,[1] very extensive salt marsh plains have been reclaimed from the sea. In time, however, nature herself will reclaim them, if the coast is not sinking.

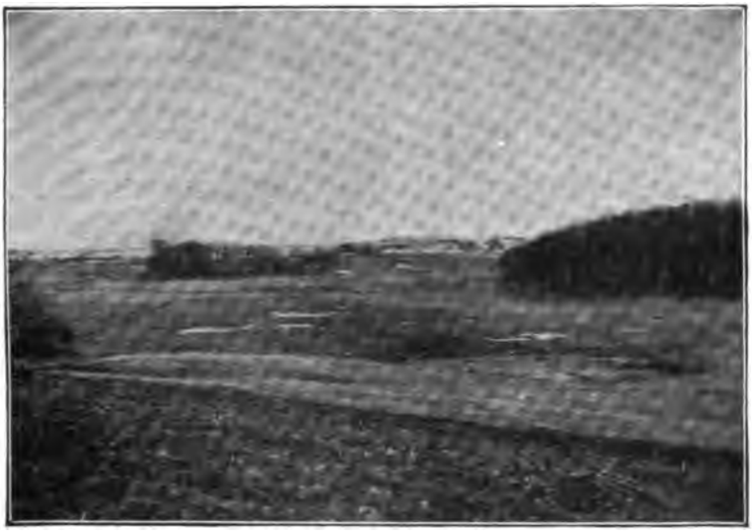

FIG. 32. Salt marsh plain at Ipswich, Mass. Wooded glacial hills rise above the plain, and the ocean sand bar, behind which it has been formed, is seen in the white hills of the background (photograph by J. L. Gardner, 2d).

Not far from the city of Brooklyn, and along the coast of New Jersey, just south of New York City, there are extensive salt marshes,[2] and all along the Long Island shore, as well as that of Connecticut to the north, there are patches of this marshy land.[1] Sometimes these grade almost imperceptibly into dry land; and habitable plains end in a salt marsh, without any sharp line of demarkation. Being nearly at sea-level, the marine plains so far described, unless elevated, can pass through no complex stages of development, but will remain as level tracts of land near sea-level, crossed by streams flowing in almost imperceptible valleys.

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[1] Smock, Annual Rept. New Jersey Geol. Survey, 1892, 313–353.

[2] Vermeule, Annual Rept. New Jersey Geol. Survey, 1896, 287–317; Cook, Geol. Survey, New Jersey: Report on Cape May County, 1857, 15–65, 91–94; Annual Rept., 1869, 23–41; Geology of New Jersey, 1868, 300–308; Annual Report, 1885, 61–70.

Raised Sea Bottoms.—Beyond the new land, the tidal currents and waves are distributing sediment over the bottom, building a plain on the ocean bed. For a distance of 75 or 100 miles from the New York and New England coasts there is such a plain of remarkable levelness, made of layers of sediment which have obscured many of the irregularities that may have once existed. If the land along this part of the continent should rise to an elevation 600 feet above the present, there would be a coastal plain sloping gradually from the present shore line to the new seashore. Such an elevated *sea-bottom plain* would be a constructional plain built by deposit and raised into the air by the forces of elevation.

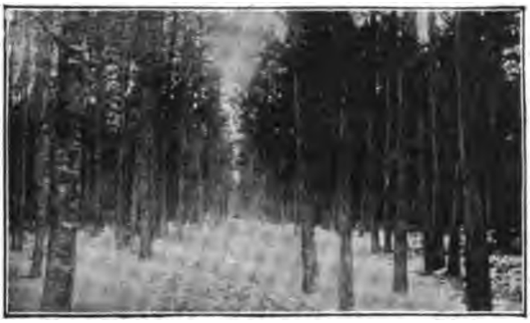

Fig. 33. In the pine-lands of New Jersey. Raised sea-bottom plain (Davis series of geographical lantern slides).

This case finds no actual present illustration within the boundaries of New York, but just south of it, in New Jersey, and from there to the Rio Grande, the lowlands bordering the coast are actually of this origin. The plain of the pine lands of New Jersey (Fig. 33) and the coastal plains[1] of the Southern and Gulf States, represent an old sea bottom slightly elevated above the ocean. That of Texas has been so recently elevated that fossils of animals now living in the Gulf are enclosed in the clays; and it is so young, and the slope is so moderate, that in places it is a great, swampy tract, with streams flowing almost on the surface of the plain.

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[1] Mather, Geol. of New York, First Dist., 1843, 17–19; 234.

While at present New York has no such plains as these, we are able to look back in time to a period when similar level tracts stretched westward from the old land which existed among the ancient Adirondack and New England mountains (p. 28). Near the close of the Paleozoic, when the Appalachians were uplifted, these *coastal plains* were elevated above the great interior sea, and they were very extensive, including the greater part of New York. It was upon these plains that the vegetation grew out of which the coal beds of Pennsylvania have been made; and it is not improbable that similar tree-covered swamps at the same time existed in New York, although now all traces have been removed by denudation. The history of this ancient plain, since that time of first uplift, has been so complex, and the record of it so battered by the attacks of the agents of denudation, that it is only by a careful study of the geology of the region that we are able to state these facts. The low plains have been raised to plateaus and greatly dissected and transformed (Fig. 41); but in the beginning they were true sea-bottom plains.

LACUSTRINE PLAINS.—*Lake-Bottom Plains.*—In lakes very nearly the same kinds of plains are made as those of the sea, and New York furnishes many illustrations of the several kinds. During the closing stages of the glacial period there was an ice dam across many of the streams; and temporary lakes existed where now there is dry land.[2]

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[1] McGee, Twelfth Annual Rept., U. S. Geol. Survey, 1891, 347-521.

[2] For the Red River plains of Dakota and Canada, see Thomas, Hayden Geol. Survey, Sixth Report, 1872, 293; Upham, Monog., U. S. Geol. Survey, Vol. XXV., 1895. For Bonneville Plain, see Gilbert, Monog., U. S. Geol. Survey, Vol. I., 1890; this lake-bottom plain is not of glacial origin.

Most of these were small, and the deposits in them have built either small plains, or else were not of sufficient duration to smooth over the lake bed. Such plains may be looked for in many of the valleys of the north-flowing streams, most of which were held back by the ice dam. However, in the case of the Great Lakes (p. 251), while the outlet through the St. Lawrence was clogged by ice, the level of the waters was so raised that at one time the outflow was past Fort Wayne, Ind., and at another past Chicago, and still later through the Mohawk in New York. The last stage existed for so long a time that extensive beaches were built. For example, beaches made during these high-water levels were constructed along the shores of both Erie and Ontario. These extend as narrow plains or ridges, really terraces, which are remarkably level and continuous.

During this stand of the water, also, deltas were constructed which now exist as broad, level-topped areas of gravel. Over the bed of the lake, sand and clay were strewn, filling some of the depressions so that the surface, already quite level, was made into a more typical plain. Therefore, south of the beach-terraces and ridges now forming on the present lake shore, and north of the ancient beaches, there are plains which were once lake bottom, and which owe some of their levelness to this fact. If Lake Erie should be drained there would be a similar, though much more extensive plain, on the site of the lake.

Lake Delta Plains.[1]—In lakes, especially the smaller ones, the water is shallow, the bottom is not sinking, and there is only slight wave action, and no marked tide. In such lakes there is less chance for the removal of sediment than in the sea. Rivers bringing their load to the ocean do not succeed in accumulating all of it near their mouths, but much of it is strewn over the sea floor, being carried hither and thither; those entering lakes quickly lose nearly all of their load, and most of it is dropped near their point of entrance. The lake filters the water of its sediment, so that the outflowing stream is pure and clear. Some of this sediment is strewn over the lake bed; but most, and the heaviest, settles near the river mouth, building a delta. Therefore opposite the mouths of most streams entering lakes there are true delta plains (Fig.112), some of which are quite extensive.

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[1] Gilbert, Monog., U. S. Geol. Survey, Vol. 1., 1890, 65–70; 153–167.

In the Finger Lakes such deltas are abundant, and at the head of each of these lakes there is a broad delta flat. These plains are not truly level, but extend beneath the lake water at their margin, are swampy near the shore, and rise gradually both from the lake shore and from the main streams toward the margins of the valley. This elevation of the surface is due to the deposit of sediment brought by the normal river floods. The town of Ithaca, at the head of Lake Cayuga (Fig. 111) is built on such a delta, and mainly on the eastern side of it. The town of Watkins, at the head of Lake Seneca, is on the western side of a similar delta. The position of these towns is due to the fact that the tributary streams from the east are more numerous in the former case, and from the west in the latter. The deposits made by these streams have elevated the surface of the delta near their mouths, and transformed it to dry land, while the opposite side is swampy. These are true, though very flat, alluvial fans.

Lake Swamp Plains.—As in the case of the sea, so in lakes, when the bed has been raised enough, vegetation commences to take root where other conditions favor. On the exposed shores of large lakes this is not possible, because the waves keep the mud and sand in movement so that the plants cannot take root; but along lake shores, as in the sea, there are bays, and there are also places protected by sand bars; and in these protected places vegetation can grow, as it can also in those small lakes in which large waves cannot be generated. By their life and death plants help to build up the lake bed, partly by their own addition, partly by the accumulation of remains of animals which thrive among the lake plants, and partly by entangling sediment and causing it to settle in the quiet water. These often transform the shores of lakes, especially small ones, to swampy plains.

Filled Lake Plains.—In the end the work above described may completely *replace* the lake by swamp (Fig. 119). A very large majority of the peat-bog swamps of New York, such as those which abound in the Adirondacks,[1] are the result of this transformation of lake to swampy plain by the filling of the lake, at first by the deposit of sediment, and later by the aid of plants. Many of these bogs have been cut into for one purpose or another, and in them one commonly finds, after passing through several feet of peat, perhaps with thin layers of marl, a bed of clay which represents the first step in filling the old lake or pond. There are thousands of acres of such plains in New York, and some of them are of large size. In Nova Scotia one may frequently see filled lake plains with a diameter of two or three miles.

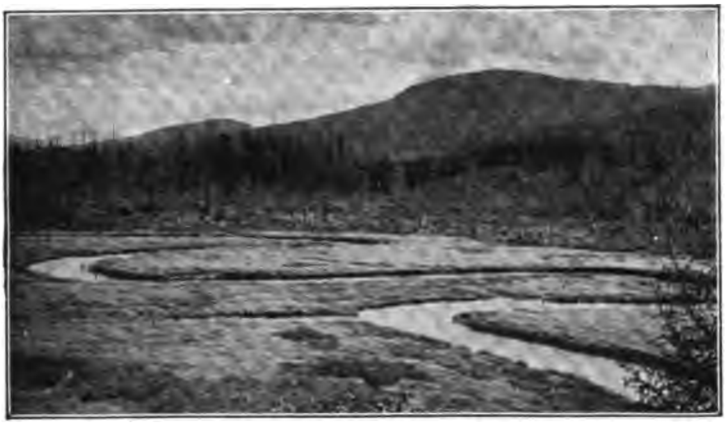

FIG. 34. Stream (Ray Brook) in the Adirondacks meandering through a filled lake plain (photograph by S. R. Stoddard, Glens Falls, N. Y.).

FLUVIATILE PLAINS.—If, for any reason, a stream flows over a level area with such a moderate slope that in time of flood all the water cannot be carried in the channel, when it overflows its banks it spreads out as a sheet of water on either side of the channel. In this lake-like expanse the current is so reduced that some of the sediment is deposited as a sheet, by means of which the irregularities are smoothed over, and a plain formed. This *floodplain* is gradually *built* up, and in time may become very extensive, as in the case of some of the great rivers of the world, like the Mississippi.

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[1] Smyth, Amer. Geol., XI. 1893, 85–90.

New York has no such great floodplains, though many streams are bordered in parts of their course by small ones. This is true, for instance, of streams flowing over deltas, or where they pass across swampy plains that have been caused by lake filling. They also exist where the river course is interrupted by deposits of glacial drift. In parts of the Hudson there are extensive, though narrow floodplains; and in the Susquehanna, Mohawk and Allegany valleys there are level areas which are true floodplains, and over which the rivers rise when in high water; but though some of these are of considerable area, they are nowhere of great extent.

These river plains may become true *terraces*,—that is, narrow plains bordered toward the river by a steeply descending bank; and often, on the side away from it, by a steeply ascending slope. These are generally due to the cutting action of the river (p. 94), but such terraces are occasionally *built up* by river floods of variable height.[1] Since none are known in New York it will be sufficient merely to mention this class.

GLACIAL PLAINS.—By these are meant plains constructed by the direct action of the ice itself. When the continental glacier extended across New York (Chapter IV), covering the entire area of the State, which was therefore transformed into a plain or plateau by the ice covering, all irregularities were submerged and there was a great *ice plateau*, like that now covering Greenland. While this ice existed, moving slowly southwards, it ground the surface somewhat, picked up a load of rock fragments, and dragged them southwards. When these reached the end of the ice, part went away in the streams furnished at the glacier's end by the melting ice, and part accumulated along the margin, forming terminal moraines. There was a constant procession of rock fragments toward this margin, and at any one time the ice held much in its grasp, firmly frozen in the bottom layers of the glacier, as we find at present in Greenland. When the ice melted, this débris—*till* or *boulder clay* it is called (Fig. 35)—was left at the place where it happened to be, so that much of the surface of New York is now covered with a coating of boulder clay, in which clay is the chief element, but scattered through which are numerous boulders of rock not to be found in any of the neighboring ledges, but dragged from the north; and upon their surface are often seen scratches which they have received on the journey. This till layer varies in thickness, sometimes barely covering the rock, or even being entirely absent, sometimes reaching a thickness of several hundred feet. In the Middle States the general till covering is very deep, so thick, in fact, that the preglacial topography has been almost obscured by it. Boring for oil and gas in Ohio and Indiana have revealed buried river valleys beneath the thick till covering of the prairies. Therefore, this part of the extensive plains of the Central States owes its levelness, in large part, to

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[1] See Tarr, Amer. Journ. Sci., XLIV., 1892, 59–61.

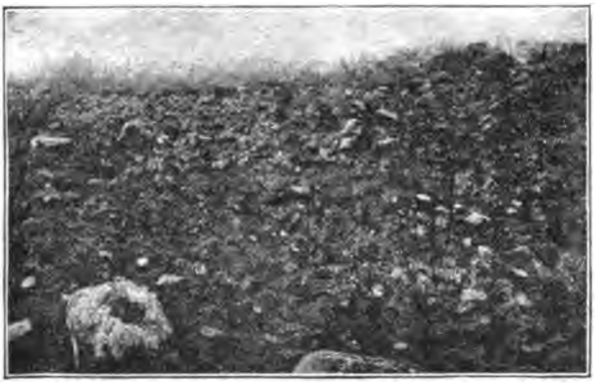
FIG. 35. Section in till or boulder clay in Pennsylvania (Lewis, Report Z, Pennsylvania Geological Survey)

the glacial deposits, and is, in consequence, a true till plain.

Most of New York is too hilly for such plains to be formed, but the glacier has greatly reduced the original irregularities, partly by cutting down the hilltops, and partly by carrying off the materials thus derived and depositing them in the valleys. There are hundreds of cases in which stream valleys have been so filled, that, after the ice left, the rivers were not able to occupy them. Some of these valleys may still be seen as sags in the surface, while others are entirely obscured, though the great majority have merely had their depth decreased by the deposit of drift. By the latter means the valley bottoms, in some cases originally one or two hundred feet deeper than at present, have been transformed to valley-bottom plains by the till filling.

In addition to this, there are narrow, terrace-like till plains, clinging to the hillsides above the valley bottoms, apparently representing deposits held *under*, or in the bottom of the ice, when the valleys were filled by the glacier, and allowed to drop down into their present position when the ice support was removed. In the hilly plateau region, near the divide of the Finger Lakes and Susquehanna, there are many terraces of this origin.

Besides these small plains, there is one extensive level area which owes at least a part of its levelness to this cause of ice filling. This is the plain which borders the Lake Ontario shore (p. 12), and which, except where roughened by irregular glacial deposits, is, in general, remarkably level. The surface of this region must have been *somewhat* level before the ice came; but presumably it was crossed by river valleys. Indeed, some of these still show, as in the case of Irondequoit Bay, which is apparently the preglacial course of the Genesee River. Practically all the valleys, however, have been obscured by the glacial deposits; and so this, which was apparently a dissected preglacial plain, is now a very regular till-covered plain.

GLACIO-FLUVIATILE PLAINS.—While the ice front stood at its farthest limit it reached into Pennsylvania, at that time covering nearly the entire area of New York; but as the glacial period waned, the ice melted, and its front gradually stood along lines farther and farther north. Wherever it remained its melting furnished the streams with great volumes of water and of sediment, thus introducing conditions quite different from those of the present and the earlier past. It may be said that this water and sediment, escaping from the ice front, passed either into streams leading *away from* the ice, or into north-flowing streams which led *toward* the ice front. In the former the water found ready escape; but in the latter it was ponded by the ice dam. In both cases deposits of interest were built by the great volume of sediment-laden water, and some of these are true plains, though usually not of large size.

Gravel-Filled Valley Plains.[1]—Where the water found a slope toward the south, either the slope was sufficient to allow the great floods to carry all of the sediment, or else it was too slight for this; and in the latter case some of the load had to be deposited. Because so much sediment was supplied, the latter was frequently the case. Even at present, at the margins of the Alpine glaciers, the streams are not able to carry all their sediment load down the steep mountain valleys; and a similar condition is found along the margin of many other glaciers, notably the Malaspina of Alaska (Fig. 36).

As a result of such conditions the streams, depositing some of their sediment, gradually built up their beds, perhaps flowing over the plain in numerous *anastomosing* channels. By this means many valleys of streams which flowed southwards from the glacier have had a deep filling of sand and gravel.[2] One may see this class of plain in many of the tributaries of the Susquehanna and Allegany.

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[1] Salisbury, Annual Rept. New Jersey Geol. Survey, 1892, 96–125

[2] Brigham, Bull. Geol. Soc. Amer., VIII, 1897, 17–30.

They are so numerous that some form of development of them may be looked for in nearly all the south sloping valleys of New York.

The influence of this kind of deposit is felt even as far as the sea. The floodplain and delta of the Mississippi contain a vast amount of sediment furnished by the melting glacier, and some of the loess of the Mississippi Valley, by which certain prairie areas have been made, doubtless had a similar origin. The building of these gravel-filled valley plains, and the prairie areas of fine-grained clay, was aided by the fact that when the ice was melting away from the country the land was lower in the north than now; for as a result of this the south-flowing streams had less grade than at present.

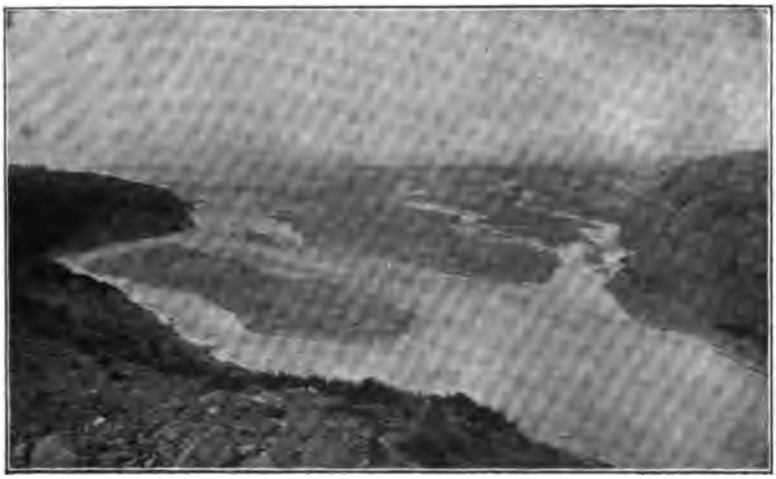

FIG. 36. Delta plain being formed at margin of Malaspina Glacier by the deposit of gravels brought by the water from the glacier, but not capable of being carried farther (photograph by Prof. I. C. Russell).

Overwash Plains.—Where the surface was moderately regular, but gradually sloping toward the south, many small streams which escaped from the ice front combined to build coalescing plains, or flat, alluvial fan deposits, to which the names *overwash plains* or *frontal aprons* have been given. Within the boundary of New York these are typically illustrated on the south side of Long Island,[1] where there are extensive sandy plains bordering the southern margin of the terminal moraine. In the more hilly region of central and western New York there was little chance for these to be formed. Their place is taken by gravel-filled valley plains, though here and there these are broad enough to be classed as frontal aprons. An illustration of this is found just southwest of Cortland, and another at Elmira and Horseheads.

Terrace Plains.[2]—In many of the stream valleys sloping southwards there are well-developed terraces, which are true plains, narrow to be sure, and sloping down stream parallel to the river. Nowhere are they better developed than in the Connecticut River valley, where, in some places, there is a series of several well-developed terraces composed of clay, sand and gravel, with level top and steep margin. In origin they are associated with the withdrawal of the ice sheet; but there are two possible explanations, one of which only (constructional) is mentioned at this point. (For the other see p. 94.) This explanation is that the sediment-laden river water was subjected to risings and shrinkings with the change of season. In winter the river was small and occupied a narrow channel. In spring it rose to a higher level and had a broader channel, the present first terrace top; in summer, rising still higher, it filled a still broader and deeper channel, etc. By this explanation it is supposed that each level of the floods occupied a channel of different breadth and depth; and, since *deposits* were being made all of the time, terraces were built, just as a *single* terrace is being made by rivers which occupy a narrow channel at ordinary stages, and a broader one during flood times when they overflow their floodplains. The floodplain is a true terrace of construction, and accordingly, if the above explanation is true, such terraces as those of the Connecticut are merely the floodplains made by former floods which rose to different levels in different seasons.

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[1] Lewis, Amer. Journ. Sci., XIII, 1877, 235; Upham, Amer. Journ. Sci., XVIII, 1879, 81-92; 197-209; Hollick, Trans., New York Acad. Sci., XIII, 1894, 123-130.

[2] Tarr, Amer. Journ. Sci., XLIV, 1892, 59-61.

Deltas.—Where the glacial streams entered valleys whose natural slope was toward the north, they were transformed into lakes in which the sediment was deposited, as it is in any lake; and since many of these lakes have now entirely disappeared, the deposits that were then made appear at present as part of the land surface. Some of these deposits have made plains like those existing around the shores of the Great Lakes (p. 80). Generally the *beach terraces* are indistinct, though they are very prominent along the ancient shores of Ontario and Erie. However, in many places, as, for instance, along the margin of the

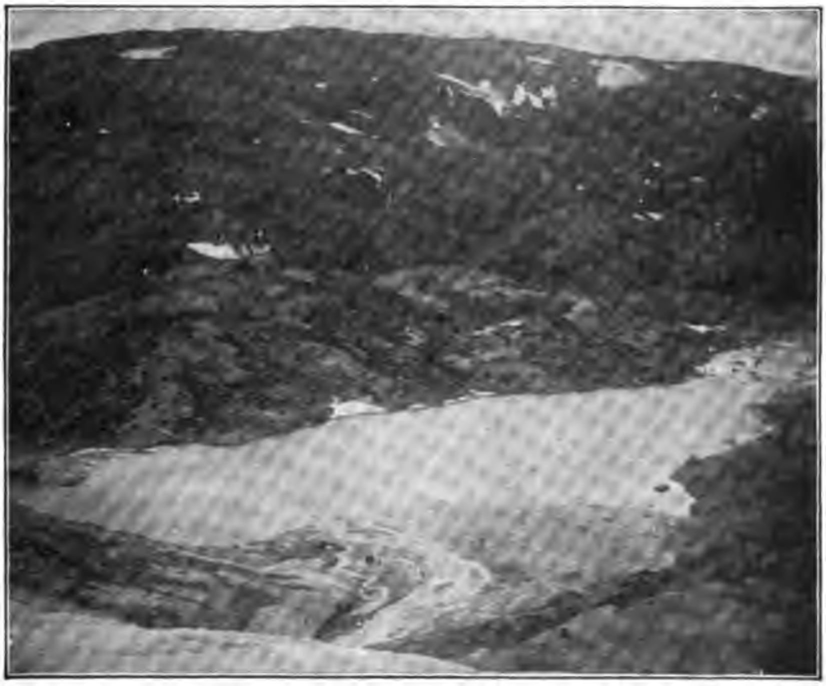

Fig. 37. Small delta being made in a lake at the margin of the Greenland ice sheet and supplied with water from that glacier.

Finger Lakes[1] and Lake Chautauqua, there are gravel terraces, quite level-topped, which border the tributary streams at various elevations above the present lake surface. These streams, flowing down the hillside, entered the lakes during their higher stages, deposited their sediment and built deltas (Fig. 38), as streams are now doing where they enter these same lakes at lower levels. They, therefore, stand as witnesses of the former higher water levels.

Sand Plains.[2]—Even more extensive plains of gravel exist here and there in positions where it is difficult to account for the source of the gravel. These *sands plains* have the form of true deltas, with level tops furrowed with numerous channels and terminating in a steep front, facing away from the former ice front. They were evidently built by the deposits made from a gravel-laden stream now extinct; and careful studies have shown that these streams came from the ice which was forming the dam for lakes now gone, as are the streams themselves. Such plains have not been described from New York, but one is found north of Geneva and another, possibly partly of this origin, near the town of Brookton, just southeast of Ithaca.

OTHER PLAINS.—During the stay of the ice upon the land, the elevation with reference to the sea-level was lower than now, and the sea entered the Hudson River at a higher level than at present. Then the streams tributary to this river entered a fjord; and, being loaded with sediment,[3] they built deltas and terrace deposits in the Hudson itself and its tributaries. In many places illustrations of these plains may be seen, as near the mouth of the Mohawk and the Catskill.[1]

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[1] Hall, Geology of New York, 4th Dist., 1843, 342–7; Lincoln, Amer. Journ. Sci., XLIV, 1892, 297; New York State Museum Report, 48, 1895, 74; Fairchild, Bull. Geol. Soc. Amer., VII, 1896, 423–452; Watson, New York State Museum Report, 51, 1897, I, r55–r117.

[2] Davis, Bull. Geol. Soc. Amer., I, 1890, 195; Gulliver, Journ. Geol., I, 1893, 803; Upham, Bull. Geol. Soc. Amer., VIII, 1897, 183.

[3] Streams then carried more sediment than now, both because the ice was furnishing them with it, and because the land from which the ice had recently disappeared had not yet been protected by vegetation, so that the rain fell upon it with something like the effect that is produced when it falls upon a road, or a plowed field, in contrast to a pasture or a forest.

In the temporary lakes not only was sediment deposited in abundance opposite stream mouths, but much was carried out into the lake and strewn over the floor,[2] which in some cases was transformed to a plain of gravel, sand or clay (p. 80). Plains of this kind are now to be seen in some of the north-sloping valleys, in which they resemble the gravel-filled valleys of south-flowing streams. In other cases, as in the Montezuma marshes (Fig. 38) at the head of Lake Cayuga, and the Connewango Swamps southeast of Jamestown, in Chautauqua County, there are extensive lake-bottom plains, still in a swampy condition.

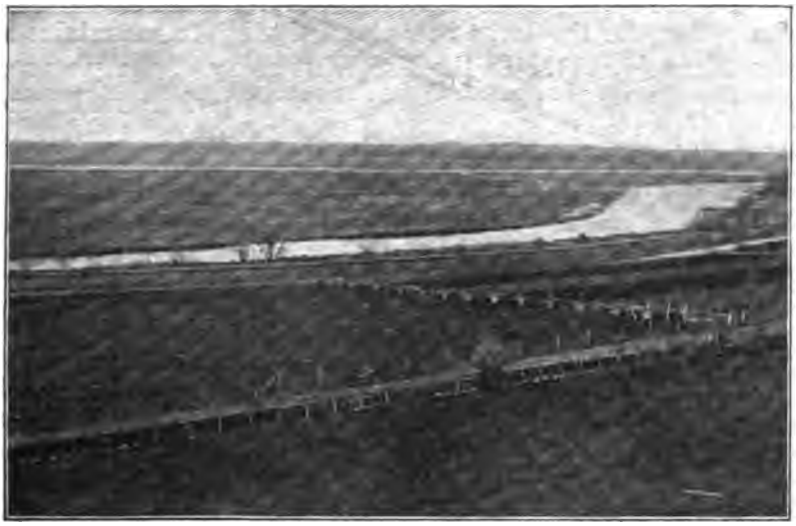

FIG. 38. The Montezuma marshes, northern end of Cayuga Lake (photograph by C. S. Downes).

VOLCANIC PLAINS.—Since New York is not a volcanic region, there are no illustrations of these plains within its boundaries, and therefore this subject may be quickly passed over. A lava flow, spreading out over a moderate slope, fills irregularities and may build a plain; and so also may volcanic ash erupted and strewn over the country on one side of the cone. Lava plains have certainly existed in the Connecticut Valley, and possibly also in New Jersey; but subsequent changes have entirely destroyed the plains, for the lavas now stand tilted into mountainous elevations (p. 61). In the Far West many of the plateaus are capped by lava flows that once were plains; and some valleys, like that of the Snake River, have been lava-filled and transformed to lava plains.

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[1] Hale, Amer. Journ. Sci., 1821, III, 72–3; Finch, same, 1826, X, 227–229; Mather, Geol. of New York, 1st Dist., 1843, 129–158; Dwight, Trans. Vassar Bros. Inst., III, 1884–5, 86–97; Davis, Proc. Boston Soc. Nat. Hist., XXV, 1892, 318–335; Ries, Trans. New York Acad. Sci., 1891, XI, 33; Merrill, Amer. Journ. Sci., 1891, XLI, 460–66; Taylor, Amer. Geol., 1892, IX, 344.

[2] Ries, Trans. New York Acad. Sci., XII, 1893, 107–109.

DESTRUCTIONAL PLAINS

WAVE-CUT PLAINS.[1] — The agents of denudation are planing down the surface of the land and carrying materials toward the sea, where extensive plains are being constructed (p. 78); and on their way these materials may halt in lake or river valley, building plains of small extent. But, in the course of this work of degradation, plains may also be formed by the very *work of destruction*, distinct from the action of building. For instance, the waves, either of lake or sea, may saw into the land, forming wave-cut plains which are generally of small extent and lie beneath the water. Later, these may, perhaps, be raised above the surface.

This horizontal planing of the land by ocean waves is believed by many to have produced grand results in the past, and this has been especially urged by the British geologists. Standing upon the tops of the hills in the Highlands of Scotland and England, it is found that they rise to nearly the same level, and it has been suggested that these hilltops are remnants of an ancient *plain of marine denudation*, formed at a time when the British Isles were at a lower level, during which the waves beat against them for such a long time that the lands were beveled. Elevation has since raised these plains, and streams have cut into them, so that only remnants of the ancient plains now remain in the form of hilltops reaching to a nearly uniform level. Since the rocks of the region are of different degrees of hardness, the explanation of the uniform hilltop level must be some condition of lower level than the present; and one possible explanation is this which has been stated. American geologists are inclined to call these remnants *peneplains*, which have resulted from denudation in the air (pp. 56 and 100).

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[1] Gilbert Monog., U. S. Geol. Survey, Vol. I, 1890, 35–36.

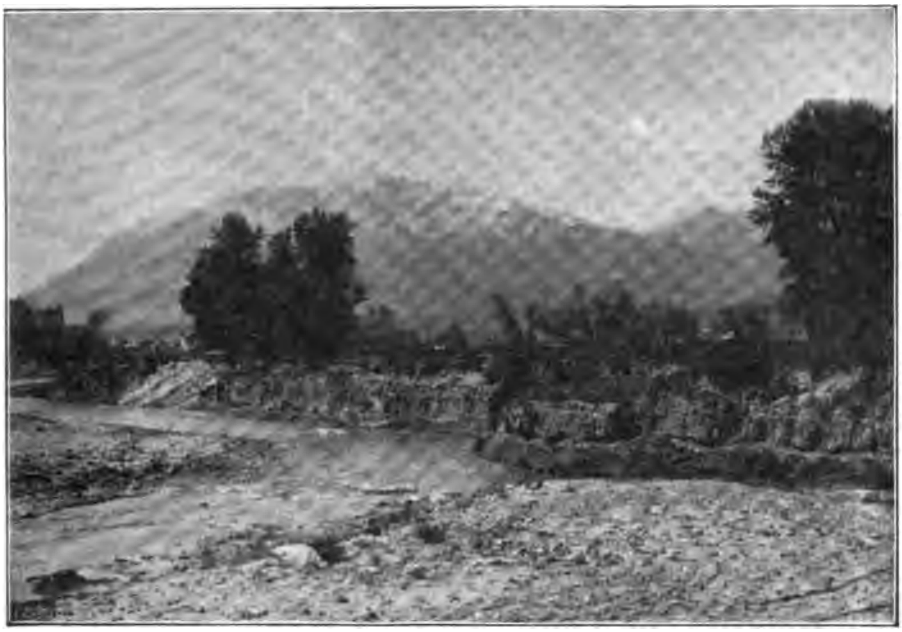

FIG. 39. To illustrate terrace formation by lateral cutting of a river, which is also cutting into its bed. There is here one terrace; but if the stream changes its position to the left, and then cuts down along its bed, a lower terrace will exist where the river bed is now located (photographed by Jackson, Denver).

RIVER-CUT PLAINS.—As they are cutting their valleys rivers are caused to meander, and the curve of meander changes gradually, so that in the course of time the river shifts its bed, having its channel now on one side of the valley and now on the other. As it swings it cuts a plain whose width is equal to the change in position. This has been called *planation*.[1]

It is by this action, it is believed, that the terraces of destructive origin are formed. According to this theory, as applied, for instance, to such a river as the Connecticut (p. 88), floods of glacial waters, instead of *building* terraces, gradually *deposit* the sediment in a sheet over the river bottom, building up an extensive gravel plain like those described above (pp. 86–88). After the sediment supply ceased, the stream began to cut a valley in the gravel plain, for the water was no longer *overburdened* with sediment, and its slope was increased by the uplift of the land in the north. Cutting a channel in one place, and then gradually swinging laterally to another point, where it remained to cut another channel, and then changed again, etc., the stream carved the gravel plain into a series of terraces.[2] Both the constructional and destructional theories apply to these gravel terraces; and since sometimes one and sometimes the other of these causes accounts for them, a study must be made of each case in order to tell which is its real explanation.

The destructional cause for terraces is the more common, and there are many terraces of this origin in New York, where the rivers have excavated their valleys in the till deposit, for which, of course, the constructional explanation is impossible. As has been stated, many of the mature valleys of New York have been partly clogged with a till filling (p. 85), in which, since the ice disappeared, the streams have been busy carving new valleys. In the course of this work they have cut terraces. The majority of small streams, as well as some larger ones, have such bordering plains extending parallel to them, and descending at the same rate as the stream bed. They can be told from others by the fact that they are made of the boulder clay, which is quite different from the stratified gravel of the gravel-filled valleys.

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[1] Gilbert, Geology of the Henry Mts., Washington, 1880, 120.

[2] Dodge, Proc. Boston Soc. Nat. Hist., Vol. XXVI, 1895, 257-273.

ICE-SCOURED PLAINS.—This is merely mentioned because no plain of this nature is known to exist in the State. In passing over the surface of a moderately regular land, the glacier will plane down the hills, leaving the surface more regular as a result of the scouring; and in the course of time, perhaps, the region might be reduced to the condition of a plain by actual ice carving.

PLAINS OF DENUDATION.—*Strata Plains.* Where rocks are nearly horizontal, as they are throughout a large part of New York, there are sheets or strata of varying hardness, one upon another. Denudation attacks these, and streams carve valleys along their lines of flow, while rain-wash and weathering more slowly wear away the interstream areas. Such a region, starting perhaps as a plain, is then much dissected, so that, looked at in detail, it has little resemblance to a true plain, but is a very hilly land, especially if its elevation above the sea is great.

However, the fact that the rocks are in horizontal sheets which are variable in their power of resistance to denudation, will make it necessary that the hill tops shall reach to nearly uniform levels. This is because, when an unusually *hard layer* is reached by the agents of denudation, further cutting is resisted so much more decidedly than in the softer strata, that the further down-cutting is held back at the level occupied by this hard horizontal bed. Thus, even if the original surface reached to different

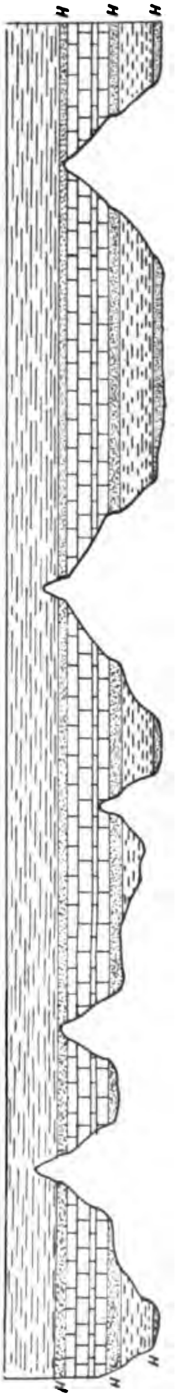

FIG. 40. Stage of youth or early maturity in a high plain or plateau with strata of variable hardness (strata marked H, hard) and, typically, in an arid climate. Contrast with stage B of figure 28.

levels, the softer rocks are removed with some ease and the harder ones less easily, so that, while further lowering is slow in the case of those places that are capped by a hard layer, other sections that are higher, but are capped by softer rocks, will wear down more rapidly, soon reaching the level of the hard layer by which the denudation is being delayed.

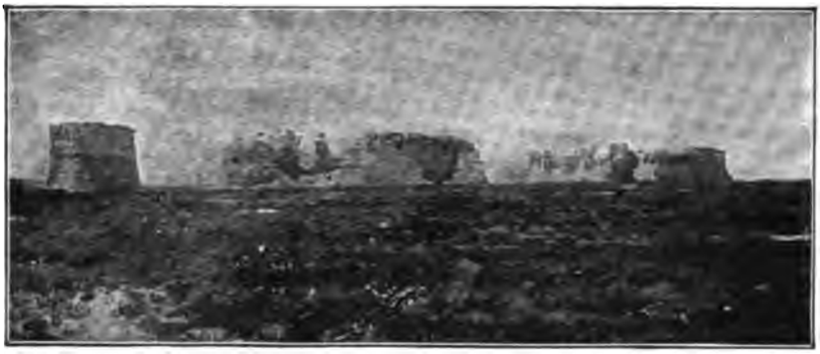

FIG. 41. Buttes on the plains of western Kansas, remnants of a higher level, left standing by denudation (photograph by Professor Williston).

In eastern New York there are plains of this origin, though they occupy rather small areas. It is this cause also which accounts for the table-lands and mesas of the plateau region of the West.[1] These level-topped areas, perhaps deeply dissected by canyons, stand up at a uniform level because of protection offered by the hard layers (Figs. 41, 42). The plains of several levels in Texas exist in horizontal strata;[2] and the plains and plateaus of central and western New York owe their present form to this condition.

The plateau of central, southern and western New York is a very hilly country, but the hills reach to a fairly uniform elevation, and many of them are nearly level-topped, (Fig. 43) so that, standing upon the crests of the higher hills, one looks across to other crests of nearly the same elevation. This is because the Upper Devonian strata are

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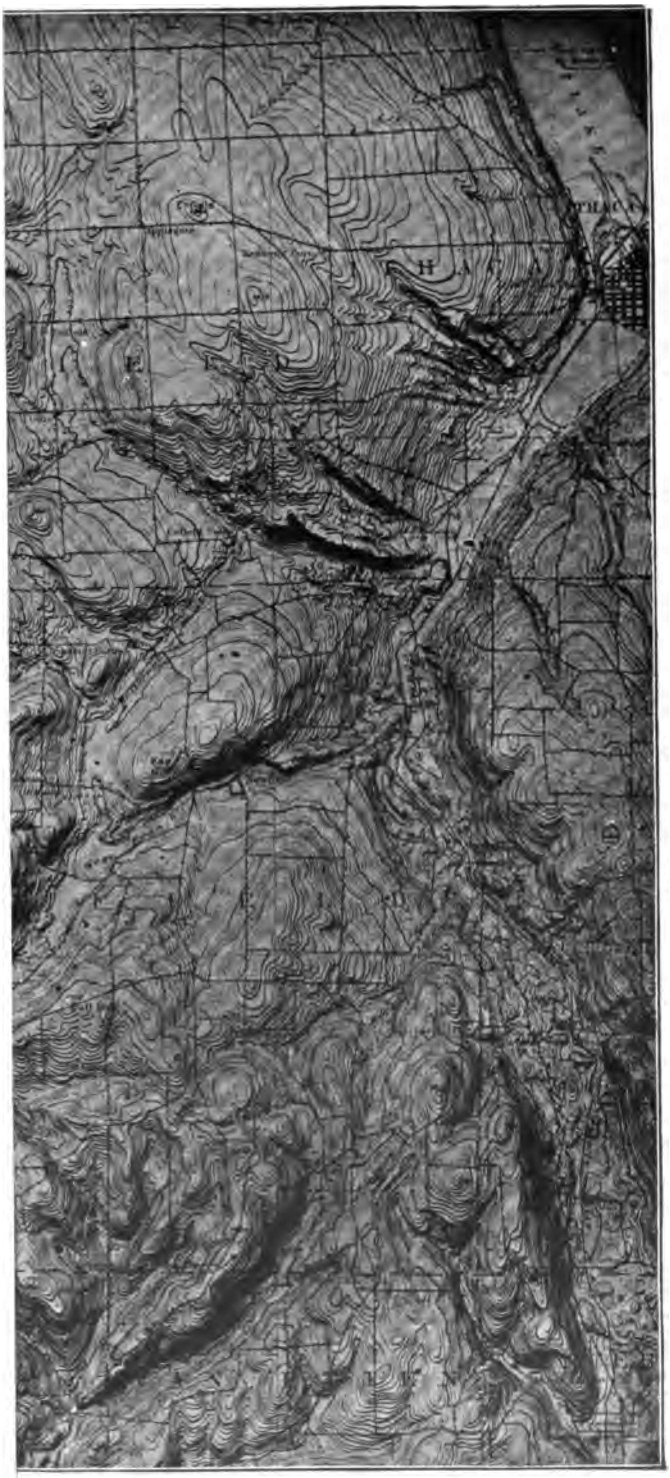
[1] Powell Exploration of the Colorado River, 1875, 1-214; Dutton, Monog. U. S. Geol. Survey, II, 1882.

[2] Hill, Amer. Geol., V, 1890, 9-29.



dissected plateau of western central New York, near Ithaca.
States Geological Survey) by William Stranahan).

coarse, sandy shales which resist the agents of denudation. In western New York, in Chautauqua County, there are two plains, (1) that in which Lake Erie is placed, which is faced on the southern side by a steep escarpment,[1] rising (2) to a hilly plateau region in which Lake Chautauqua is situated. At present there seems to be in the rock structure no definite reason for this upland plateau and for the escarpment which separates it from the lower plain; but in southern Chautauqua County, and across the line, in Pennsylvania, there are remnants of a conglomerate bed (p. 27), now remaining upon the surface in the form of "rock cities,"[2] where the great blocks, loosened by weathering, and perhaps somewhat disturbed by glacial action, now stand in confused, and often fantastic arrangement upon the surface of the land (Fig. 44). The former extension of this conglomerate may account for the plateau and its steep north-facing escarpment.

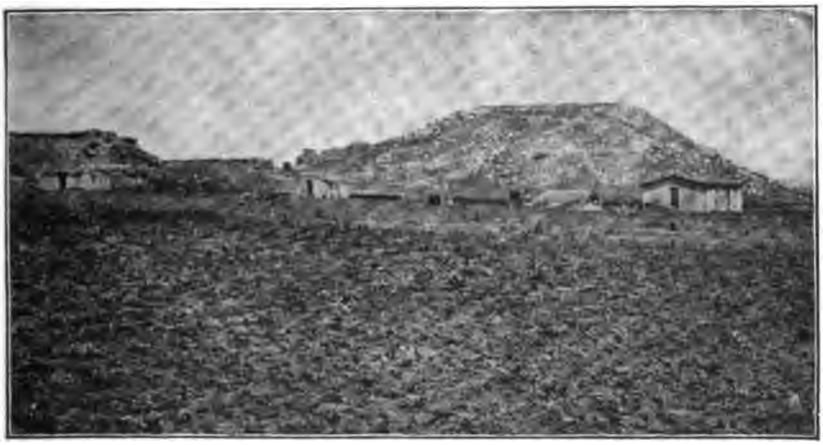


Fig. 42. To illustrate the process of destruction of a plain in western Kansas where hills capped by a hard layer are being separated to form buttes like those in Fig. 41 (photograph by Professor Williston).

At the base of the Lake Erie escarpment, on the northern border of the plateau just described, there is another plain (p. 9), of which the bottom of Lake Erie forms a part. In New York a narrow portion of this plain occupies the area between the escarpment and the shores of Lake Erie; and upon it the City of Buffalo is situated. In this region the plain is broad and fairly level, disappearing gradually under the lake toward the west, and losing its character toward the south as it ascends to merge into the high plateau of southwestern New York. As it extends eastward it gradually loses its typical character as a plain, and toward the north ends abruptly in the escarpment (Fig. 45) at Lewiston, Lockport, etc. This escarpment is determined by the presence of the hard Niagara limestone, which is also the cause for the Falls; and the plain itself, in its most typical portion, owes its levelness to the presence of this and other hard layers of nearly horizontal rocks.

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[1] Tarr, Bull. 109, Cornell Univ. Agri. Experiment Station, 1896, 92.

[2] Hall, Geol. of New York, 4th Dist., 1843, 284–285; Carll, Second Geol. Survey, Pennsylvania, Report III, 1880, 57–79; Same, Report IIII, 1883, 195–208.

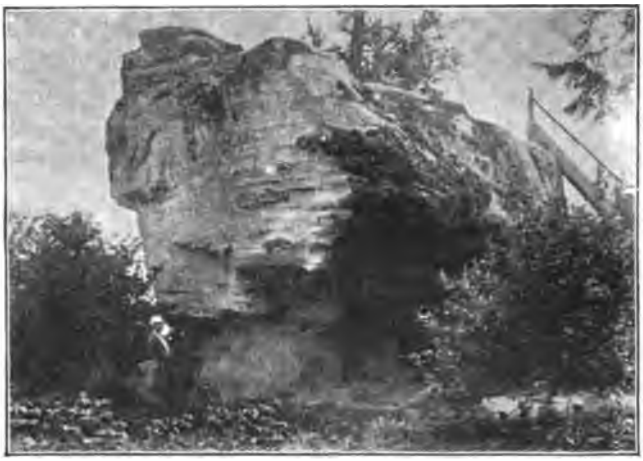

FIG. 44. Conglomerate boulder—a part of one of the "rock cities."

Below the plain just mentioned, at the base of the north-facing Niagara escarpment, is another plain (Fig. 45) which itself is terminated by a north-facing bluff under the waters of Lake Ontario, the position of this being determined by the presence of the horizontal beds of the very durable Medina sandstone. This is one of the largest and most perfect plains in the State. From Lewiston to

Irondequoit Bay, and from the lake shore to the Niagara escarpment, which loses prominence toward the east, there is a wonderfully level plain crossed by the Rome, Watertown and Ogdensburg railway.

The *general* levelness of this plain is due to the rock structure; but there is a peculiar fact about it, the real explanation of which is not certain. The Niagara and Lake Erie escarpments are trenched by *deep* valleys of preglacial origin, the positions of which are now plainly apparent in the topography, and the two plains which these escarpments bound are also dissected; but the western Ontario plain is not furrowed by such valleys. In its deepest point the bottom of Lake Ontario is about 738 feet below the lake level, and hence somewhat more than this below the level of the Ontario plain.

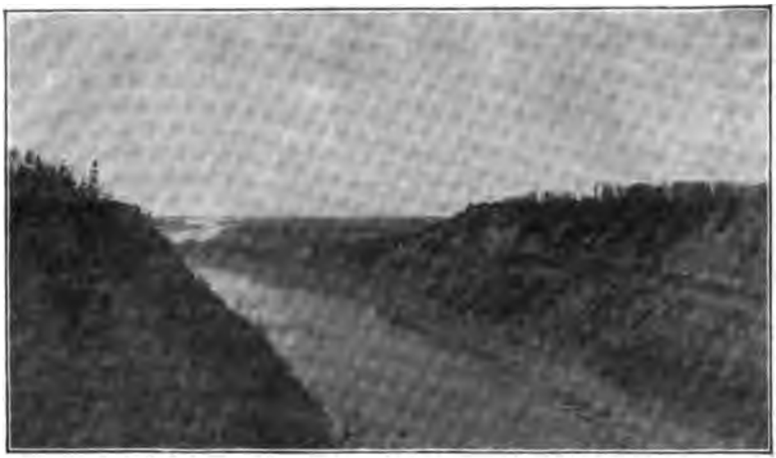

Fig. 45. End of Niagara gorge showing the Niagara escarpment and the northern end of the upper plain, with the Ontario plain stretching northward from the base of the escarpment and crossed by the Niagara river below the gorge (photograph by J. O. Martin).

There are two prominent theories to account for the basin of Lake Ontario, one that the continental glacier carved it out of the rock, the other that it was a preglacial river valley changed to a lake by various causes such as drift dams and warping, but without marked ice erosion. If the latter is true, and the bottom of Lake Ontario is an old river valley at approximately the same depth which it had before the Glacial Period, the Ontario plain during this time must have been crossed by good-sized valleys of streams which entered this ancient and very deep valley. Since they are now invisible, it must be supposed that the glacial drift has obscured the preglacial irregularities, and that the plain is therefore only in part due to destructional origin, and in considerable part a plain of construction as the result of drift deposit (p. 85).

The alternative is, that the old surface to the north of the plain, that is, the site of the present lake, was a preglacial valley, whose bottom was not much lower than the present lake level, having since been reduced to the present level by some cause. There are three possible causes for its deepening,— ice erosion, faulting and folding. Of the two latter there is no proof whatsoever; but in favor of the former we have the fact that the *ice* has actually passed over this surface. No attempt is made at this point to further discuss this question (p. 232), though it may be said that facts point more strongly toward ice erosion than toward the other explanation. If that is the real explanation, then before the Glacial Period there existed here a much broader river-bottom plain, occupying the space now filled by the waters of Lake Ontario, and with its central line not much lower than the present level of the lake's surface.

PENEPLAINS[1] (see also p. 55).—Standing on the top of the hills in the Highlands of New Jersey, or of southern New England, it is found that though the rocks are folded and disturbed, some of the hilltops reach to a nearly uniform level, as they do in parts of Great Britain (p. 92). In Britain the explanation of this fact has been marine denudation; but in this country it is ascribed to denudation in the air, or ***subaerial denudation.*** If the land remained at a nearly uniform level for a long enough time, even the highest mountains would be planed down nearly to sea-level, or to ***base-level.*** In proof of this may be mentioned the fact that New York City is situated in a low hilly region which represents the last remnants of a once elevated mountain system, as do the hills of Connecticut, eastern Massachusetts and the Highlands of New Jersey.

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[1] Davis, Amer. Journ. Sci. XXXVII, 1889, 430; Davis and Wood, Proc. Boston Soc. Nat. Hist., XXIV, 1888–1889, 365–423; Davis, Bull. Geol. Soc. Amer. II, 1891, 545; National Geog. Mag., V, 1893, 68; Bull. Geol. Soc. Amer. VII, 1896, 377; Nat. Geog. Mono., I, 1896, 269; Tarr, Amer. Geol., XXI, 1898, 351–370; Davis, Amer. Geol., XXIII, 1899, 207–239; Daly, Amer. Nat. XXXIII, 1899, 127–138; Smith, University California, Bull. Dept. Geol, II, 1899, 155–178.

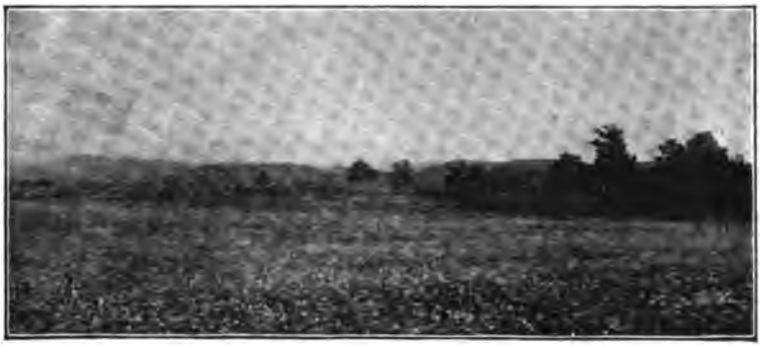

FIG. 46. A view across the peneplain of New England (photograph by J. Ritchie, Jr.).

It is difficult to account for the uniformity of level of these hills on any other supposition than that at one time they were at a lower level with reference to the sea, having been either beveled down to a hilly lowland condition or else to the condition of a plain, a ***peneplain.***[1] The reasons for this conclusion are as follows. It is known that the country was originally mountainous, because the rocks are very complexly folded; and these contorted strata vary in hardness. Therefore, at first, tilted rocks of different kinds were raised to ***different*** heights. At present, in many cases, they stand, still at an elevation of one or two thousand feet above the sea, but with the hilltops reaching to a rather *uniform* level, while between them there are valleys of no very great width. In all the time required to lower the surface so far, the result should have been the production of valleys with great width, and therefore with mature form, while between them should rise hills of different elevations. To have brought nearly all of the peaks down to a nearly uniform level, their general elevation must have been reduced even lower than now; and the fact that the stream valleys at present are *not* broad or mature, shows that there has been a rather recent uplift.

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[1] This might have been done by marine denudation or by subaerial denudation. For a critical discussion of this subject with numerous references to the literature, see Davis, National Geog. Monog. I, 1896, 269.

Therefore the peneplain theory is, that the mountains were beveled to the condition of a lowland, in fact nearly to that of a plain, at a time when the land elevation had remained nearly uniform for long periods. The surface was then uplifted, the streams began to cut deep valleys, and the old plain was so dissected that only a few remnants of it now remain in the hilltops, and these tell of a former plain by the fact that they reach to nearly the same level.

During this time of ancient base-leveling, New York was also subjected to reduction, the Adirondacks and other mountains being lowered, and the New York-Pennsylvania plateau being reduced to a plain standing nearly at sea-level. An elevation ended this period of base-leveling, and by this the streams were once more given a steep slope. Since then they have cut their valleys so deeply into the plain, and weathering has broadened them so much, that the ancient peneplain is nearly destroyed, so that, so far as New York is concerned, there is little if any evidence left of this former peneplain condition, though the evidence of former reduction is found in the bordering States.[1]

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[1] Personally I do not accept this peneplain theory as fully established, but hold it as a working hypothesis. It has certainly been applied in many very doubtful cases, but this is not the proper place for a discussion of the subject. (See references on page 56).

CHAPTER IV

THE INFLUENCE OF THE GLACIAL PERIOD UPON TOPOGRAPHY

INTRODUCTION.—When the Geological Survey of New York was undertaken, considerably more than half a century ago, the belief was current that the State had been overrun by great floods of water which had strewn the surface with the various deposits of boulders, gravel and clay which are so noticeable throughout the State.[1] Then came the glacial theory of Agassiz, at first vigorously opposed, but gradually accepted, until at present it is all but universally adopted as the real explanation of the phenomena formerly ascribed to the flood.

The farmers of the State till a soil brought to their land by an ice sheet of vast proportions, greater by several times than that now covering the great continental island of Greenland with 500,000 square miles of ice. They remove from their fields the boulders brought by the ice from the north, perhaps from even beyond the confines of the country, and they look upon a landscape modified, or perhaps even moulded, or entirely made, by this ice sheet. The lakes, the swamps, the gorges and the waterfalls have come to be what they are because of this glaciation; and the economic development of the State has depended in very large measure upon the visit of the ice sheet. Without this visit the industries, cities and people would have been very different.

Much interest has been aroused in the problems presented for solution by this latest great physiographic factor in the development of topography. Upon these problems much work has been done; but much remains still undone. New York State, though supporting a geological survey with some continuity for more than half a century, the results of which in one or two directions have been of the best, has almost totally neglected this important subject. Therefore, barring a few scattered individual efforts, and a single Government publication, almost nothing has been done to put before the people of the State the physiographic facts concerning their own environment. The farmer who would know the cause for his soils, or the teacher who would learn the meaning of the hills surrounding the school, or of the gorge or lake near by, can find no place in which to look for an answer to his queries. This discussion is bound therefore to be very inadequate because little is known.[1]

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[1] See Eaton, Amer. Journ. Sci., XII, 1827, 17–20; Dewey, Amer. Journ. Sci., XXXVII, 1839, 240–242; Same, XLIV, 1843, 146–50; Emmons, Geol. of New York, Second Dist., 1842, 422–427; Hall, Same, Fourth Dist., 1843, 318–341; Mather, Same, First Dist., 1843, 158–228; Vanuxem, Same, Third Dist., 1842, 212–224; 244–247; Lloyd, Quart. Journ. Geol. Soc., XXXII, 1876, 76–79.

BEFORE THE GLACIAL PERIOD. — Without careful and wide-extended study it would be impossible to tell in detail what the condition of New York was before the glacial period. This much is certain, however, that most of the larger features of land-form were then much as they are now. There was then an Adirondack Mountain mass, a Catskill Mountain group, and a dissected plateau in western and central New York; and each of these sections was then cut into hills and valleys, very much as they are now. The larger stream valleys, such as the Hudson, the Mohawk, and the Susquehanna, and also most of the smaller tributaries of these, then existed, although the details of stream course were in many instances very different from the present. Some rivers now flow into different valleys from those which they formerly entered, and a still greater number flow in different parts of their old valleys, perhaps upon one side of the former course. The ice has planed down some of the hills to slightly lower levels than formerly, and rounded off still others, while the valleys have in many places been clogged, or in some cases even entirely filled, with glacial deposits.

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[1] For statement of some of the principles of glacial geology reference may be made to Wright's Ice Age in North America; Wright's Man and the Glacial Period; Geikie's The Great Ice Age; and Salisbury's discussion in the Annual Report of the State Geologist of New Jersey, for 1891, 35–108.

But the most marked difference between the New York of to-day and the pre-glacial New York is in the introduction of numerous lakes. One could not safely assert that there were formerly *no* lakes in the State; but upon every physiographic argument that can be made, the existence of any but the smallest lakes seems highly improbable. Lakes must have a cause, and lake-making causes had apparently not been extensively in operation immediately before the glacial period. Therefore, the lakes, Champlain, Ontario, Erie, Chautauqua, the Finger Lakes, and the thousands of smaller ones, were probably not present. Of the larger number of these it may be stated positively that they did not then exist, for their cause is certainly glacial action.

At some time before the glacial period, the general altitude of the State was very different, being considerably higher above sea-level. Whether this was true at the very time when the ice encroached upon the region cannot be so certainly stated, though there is much reason for believing that, as the ice gradually advanced, the land was standing higher above the sea than now.

Notwithstanding these differences between the present and past, could we have an accurate large-scale model of New York State, representing the conditions of preglacial times, one would have no difficulty in recognizing the *general* topography of the region in which he dwells. The general elevation might be higher than at present, and some of the hills higher above the valley bottoms. Some valleys may now be deeper than formerly; and, as a result of the glacial deposits, some now absent would then be present, and some gorges now existing would not appear upon the model. The course of some of the rivers would be different, and most if not all of the gorges, waterfalls and lakes would not be found, the site of the lakes being then valleys occupied by running water. Probably, also, the coast line was different in an important way. If the land were then higher, the coast line must have been somewhere to the eastward of its present position. So, it follows that while there were many differences, some of them very striking, they were not so numerous as to make the general topography unrecognizable.

THE ADVANCE OF THE ICE SHEET.—Over this land the ice front slowly but irresistibly advanced, fed from some center in the far north, evidently in the vicinity of the Labrador Peninsula, from which the ice radiated outward in all directions, as the Greenland ice sheet of to-day radiates from a center somewhere within that great ice-covered land area. Why the glacier came cannot now be stated; nor can we say when it began, nor how long it stayed, nor when, nor why it went. Speculations upon these points are abundant, but they have been of little value in reaching definite and well-proved conclusions. The *fact* of the coming and going is all that can be stated with positiveness in this connection.

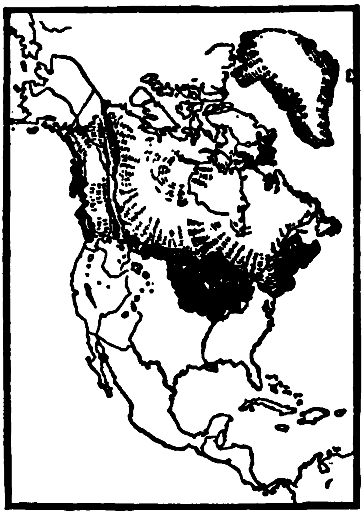

FIG. 47. To show probable extent of American ice sheets (Chamberlin in Geikie's Great Ice Age).

As the ice gradually moved southward, involving States at present temperate in climate, and before the glacial period even warmer than now, there must have been a refrigeration of climate, partly due to the *presence* of the ice, and partly to the causes upon which the formation of the great continental glacier depended. At first, upon the high mountains, the winter snows must have lasted longer and longer into the summer, until the protected valleys held some of the snow throughout the entire season. At this time valley-glaciers, somewhat like those of the Alps,

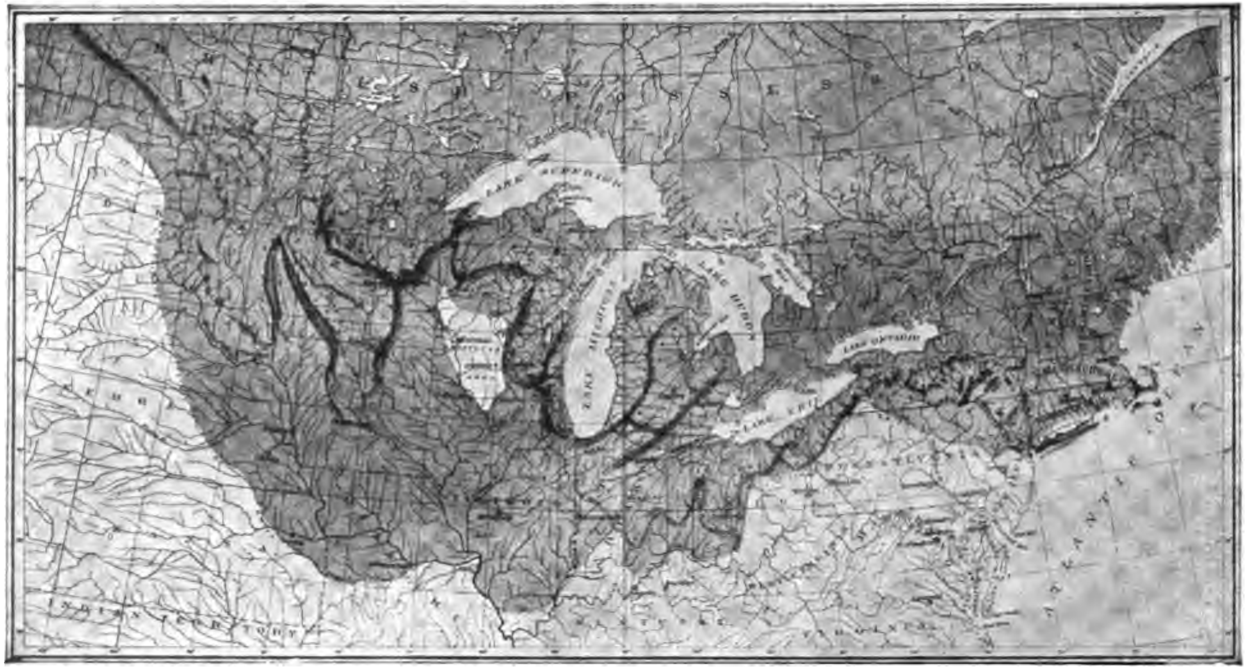

FIG. 48. To show approximate extent of ice sheet in eastern United States. "Moraine of Second Glacial Epoch" shown by heavy shading (Chamberlin).

probably appeared in the Adirondacks and Catskills, growing larger as time passed, and finally adding their supply to that of the great glacier from the north. This rose higher and higher upon the mountain sides, until, finally, the highest peaks of the Adirondacks and Catskills were submerged in the onmoving flood of ice, and all of New York State, with the exception of a small tract in the extreme western part, was transformed to a great ice plateau like that of Greenland to-day. From Labrador to Pennsylvania no land appeared above the ice-covering, whose depth was certainly greater than a mile in some places. At present no similar ice sheet exists, unless, possibly, the one in the South Polar regions, about which almost nothing is known.

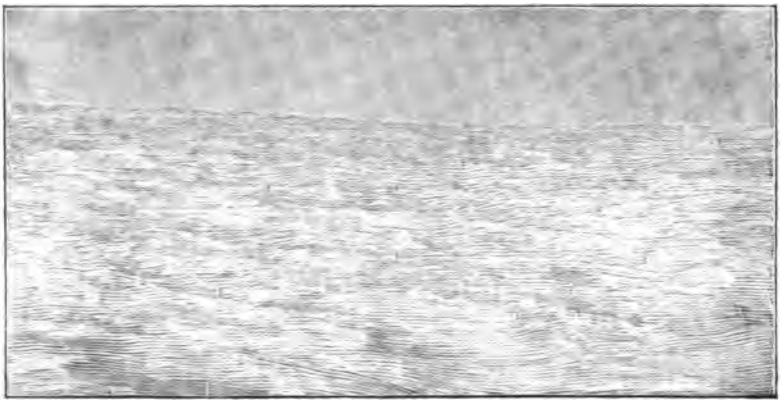

FIG. 49. Surface of the Greenland ice plateau (photograph by J. O. Martin).

With the advance of the ice, plants were exterminated, and animals either exterminated or driven to the southward. For a long time these conditions lasted, though how long, no one can now say; and year by year the ice advanced through the valleys and over the hills and even over the mountain tops. At first it swept off the soil and loose rock fragments, dragging them southward, and grinding them finer by rubbing particle against particle, or against the rock over which the glacier was slowly gliding. Valleys were deepened somewhat and hills scoured by this great force of erosion, the hills losing some of their height and being rounded. The pebbles that the ice held, and the bed-rock over which they were dragged were grooved, scratched, and polished; and at all times during the stay of the ice, the glacier contained in its mass a load of rock fragments, varying in size from boulders to clay particles, all slowly journeying southward with the ice, and being ground as they went.

At the margin, land appeared above the ice. Some distance from the front the only land was the occasional isolated hill, which reached above the ice surface, as the mountain peaks of Greenland project above its great glacier, forming the nunataks of that region. Nearer the margin ranges of hills separated projecting tongues of the glacier front,— small valley lobes projecting further southward along the valleys. The margin was evidently serrated

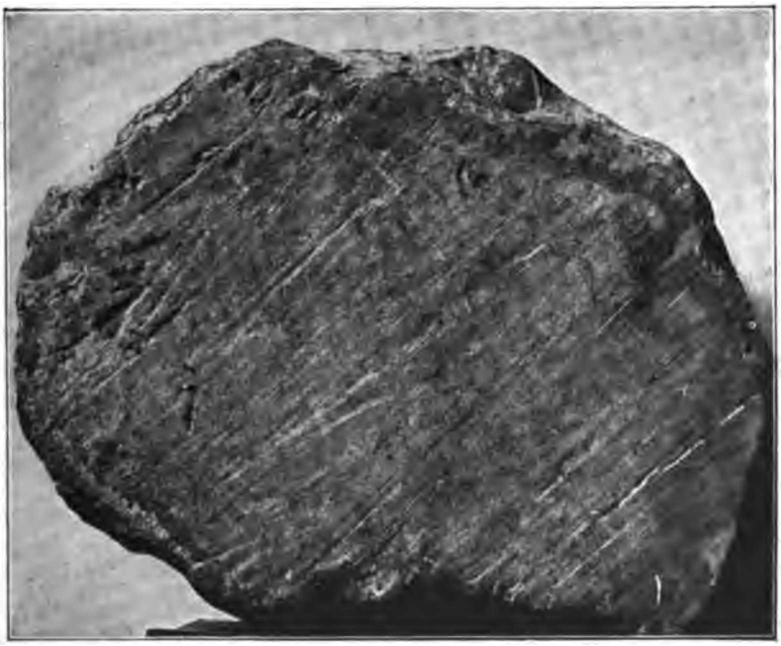

FIG. 50. A glacially scratched pebble (photograph by United States Geological Survey).

or lobate, and the reason for the position of the margin at any given point was that there the ice supply just equaled the ability of the sun and air to melt it.

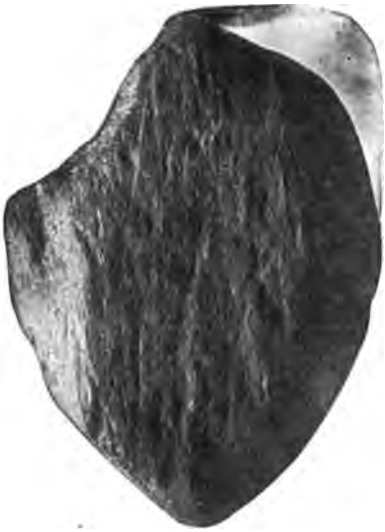

FIG. 51. A scratched pebble taken from the ice of the Greenland glacier.

Along this margin, as along the margin of all glaciers on the land, there were vast floods of water poured upon the hillsides and gathered into the valleys. Here was supplied to river valleys the rainfall of other drainage systems far to the north. Some, falling where it now escapes into the Arctic waters or the St. Lawrence system, then passed on and entered the Susquehanna, or further west, the Upper Allegany, whence it was led to the Gulf of Mexico. As a result, many small stream valleys then carried large volumes of water. Sometimes the front of the ice was not in a valley sloping away from it, but toward it, and then, in such north-sloping valleys, glacial

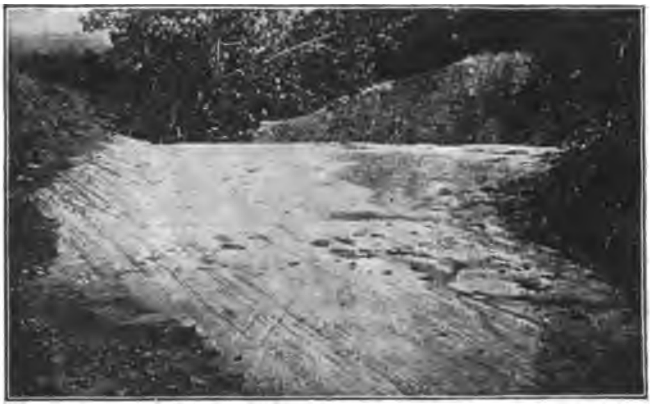

FIG. 52. Glacial scratches on bed rock (Calvin, Iowa Geological Survey).

lakes were ponded back in places where now no lakes exist. The records of these are abundant (p. 131). In the north-sloping valleys this water was iceberg-laden, and everywhere, where it started from the ice, was ice-cold, so that, flowing into more temperate latitudes, it must have produced a very important influence upon the climate of parts of the South, especially along the Mississippi Valley, nearly all of the headwaters of which were supplying this ice-derived water.

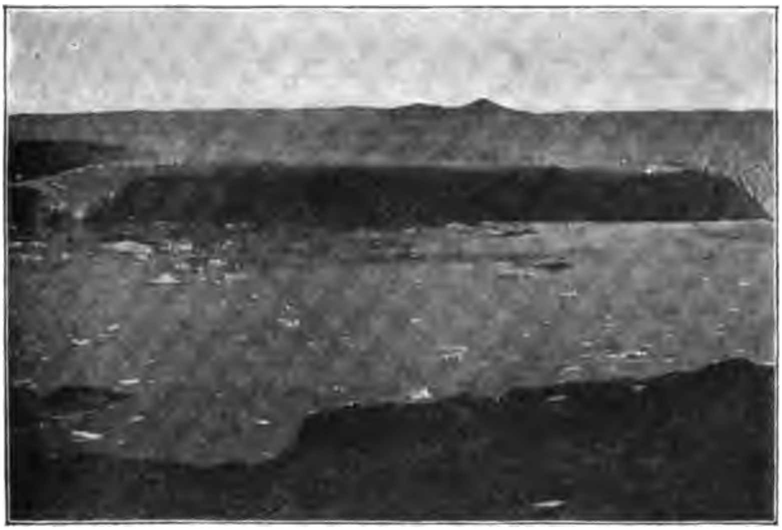

FIG. 53. A nunatak rising above the Greenland ice plateau, Cornell glacier (photograph by J. O. Martin).

Not merely was *water* supplied to the streams, but much rock material also; for this too was constantly moving on with the ice to the place of melting. Some of the sediment entered temporary marginal lakes, forming lake deposits, and some passed off in rivers, forming various types of river deposits (p. 130), often in valleys in which the rivers are not now depositing sediment. Not all of this rock load could go off in the streams, but much fell to the base of the ice, or remained in its place beneath the glacier. If the front of the glacier remained for a long time in approximately one place, as it did year by year, this dumping of rock fragments continued until perhaps a great accumulation was made, forming a moraine. The former position of the ice front may now be traced by these moraine hills and ridges, which extend across the country as indicated in the accompanying maps. The moraine formed upon the land is quite like that now being made at the margins of existing glaciers.

While throughout most of New York State the southernmost stand of the glacier front was upon the land, it is quite possible that the front in the Long Island region was at one time in the sea, as it certainly was farther east off the New England coast. In this case the glacial deposits were then dumped in the ocean near the ice margin; but many of the finer particles that could be floated away were removed by currents, while much material, both fine and coarse, was removed by the numerous icebergs which must have broken from the glacier front.

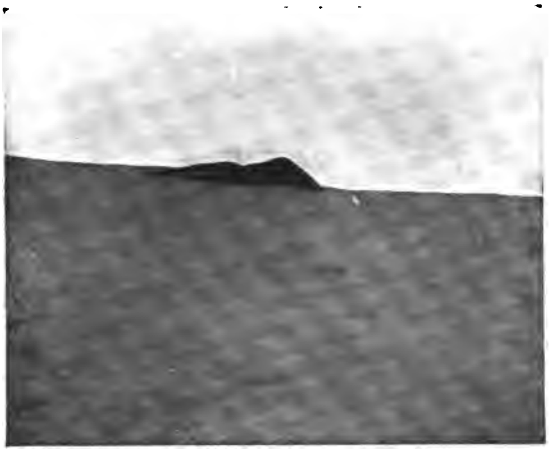

FIG. 54. A view over the great ice plateau of Greenland with a mountain peak, or nunatak, projecting above it.

THE RECESSION OF THE ICE SHEET.—In time the conditions which gave rise to the Glacial Period began to change, and the ice supply was no longer able to maintain the ice front at the southernmost limit.[1] Then this line was abandoned and the ice front slowly melted back, uncovering the country over which it had formerly advanced.

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[1] No attempt is made here to consider the question whether there was one or several advances of the ice, partly because it is still an open question, but chiefly because its bearing upon the physiography of New York is not known.

This retreat or recession was intermittent, for we find evidence that at certain places the ice halted, and the front remained long enough to build terminal moraines, or *moraines of recession*, closely resembling that formed at the outermost terminus. Thus, for instance, after having passed well down into Pennsylvania,[1] the ice halted for a long time along the line of the so-called "Moraine of the Second Glacial Epoch," which is shown for central New York upon the map (Fig. 58).[2] Numerous other halts were made, as shown by the map of western New York moraines (Fig. 59).[3] Each of these halts is marked by a more or less well-defined moraine, formed at the terminus of the receding glacier. During the time of formation of these

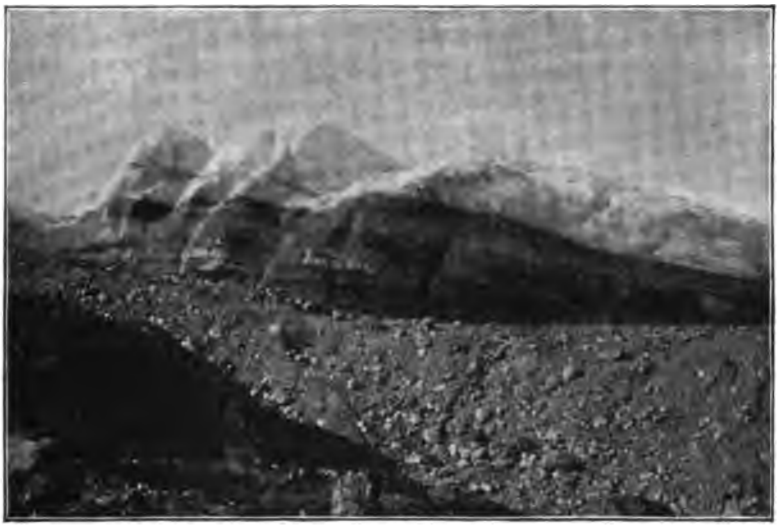

FIG. 55. Land margin, Cornell glacier, Greenland, showing débris-laden ice layers near the base, and terminal moraine in the foreground (photograph by J. O. Martin).

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[1] Lewis, Proc. Amer. Phil. Soc. XX, 1882–3, 662; Proc. Amer. Assoc. Adv. Sci. XXXI, 1882, 389–98; Amer. Journ. Sci. Ser. III, XXVIII, 1884, 276–285; Report Z, 2d Geol. Survey Pennsylvania; Wright, Bull. 58, U. S. Geol. Survey, 1890.

[2] Chamberlin, Trans. Wisconsin Acad. Sci. IV, 1876–7, 201–234; Amer. Journ. Sci. Ser. III, XXIV, 1882, 93–97; Third Annual Report, U. S. Geol. Survey, 1883, 291–402.

[3] Leverett, Amer. Journ. Sci. Ser. III, L, 1895, 1–20.

moraines the conditions at the ice front must have been closely like those described for the southernmost margin. Between these successive moraines the glacial recession must have been relatively rapid, for the front did not stand in any one place for a long enough time to permit the dragging of *débris* to the ice front in sufficient quantity to accumulate morainic hills.

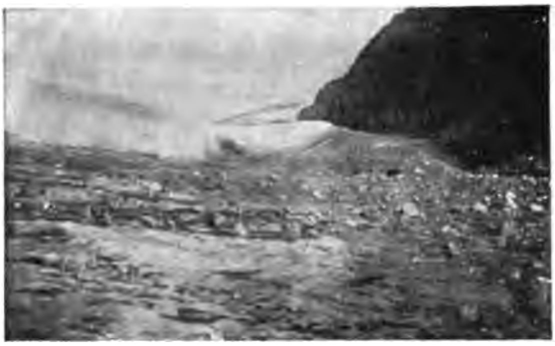

Fig. 56. The edge of a part of the great Greenland ice sheet (on the left) resting on the land, over which are strewn many boulders brought by the ice and left there when it melted.

Thus it is seen that in New York State the ice front first *advanced* across the surface, visiting each part of the State; but the record of what it then did was mostly destroyed by its continued advance over all points excepting over the deposits at the southernmost margin. Then followed the ice *withdrawal*, during which each part of the State was

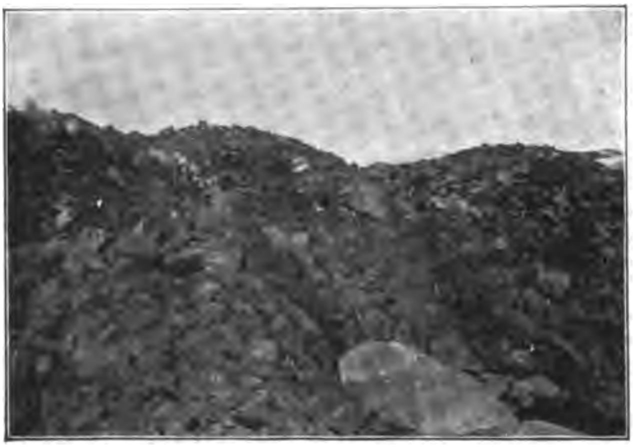

Fig. 57. Bouldery terminal moraine at margin of Cornell glacier, Greenland (photograph by J. O. Martin).

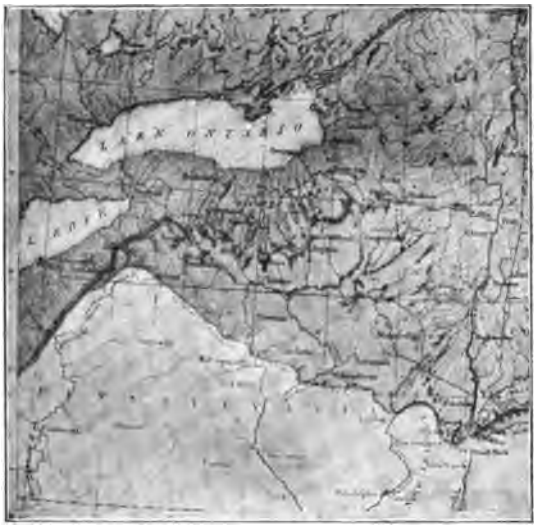

Fig. 58. To show general extent of ice in New York. Southern limit of shading marks the position of the outermost terminal moraine of Lewis and Wright, the heavy shading the so-called "Moraine of the Second Glacial Epoch" (Chamberlin).

again visited by the glacier front, this time, however, leaving a record of its visit which can now be read, especially at those places where the ice front lingered for a while and built moraines.

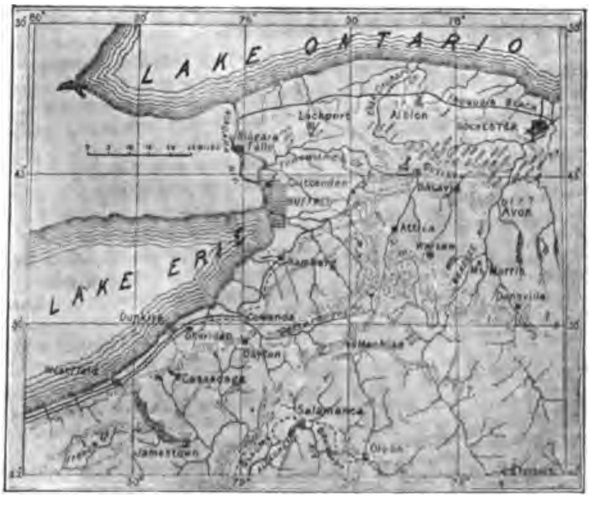

Fig. 59. Map of moraines in western New York. Direction of ice movement shown by arrows. Drumlins marked south of Rochester. Old beach line shown along Erie and Ontario shores (Leverett).

Thus it came about that moraines were formed at various points in New York, and that all over the State, every here and there, the water from the melting ice made deposits of gravel and clay derived from the glacier. These deposits, being made by water, are assorted and stratified. All glacial deposits are called *drift*, a name inherited from the time when they were explained as flood deposits. The water deposits are called ***stratified drift***, or sometimes ***modified drift***, because they are not deposits direct from the ice, but modified through the intervention of water. Naturally the stratified drift is most commonly found in valleys, for it was there that the water went; but it is not *confined* to the valleys, for many a stream from the ice top, or from beneath the glacier, reached the edge of the glacier upon a hillside, or even, in some cases, upon a hilltop. Not only does the position vary, but the depth also, though, in general, the stratified drift is deepest in the valleys, being in some cases two or three hundred feet deep.

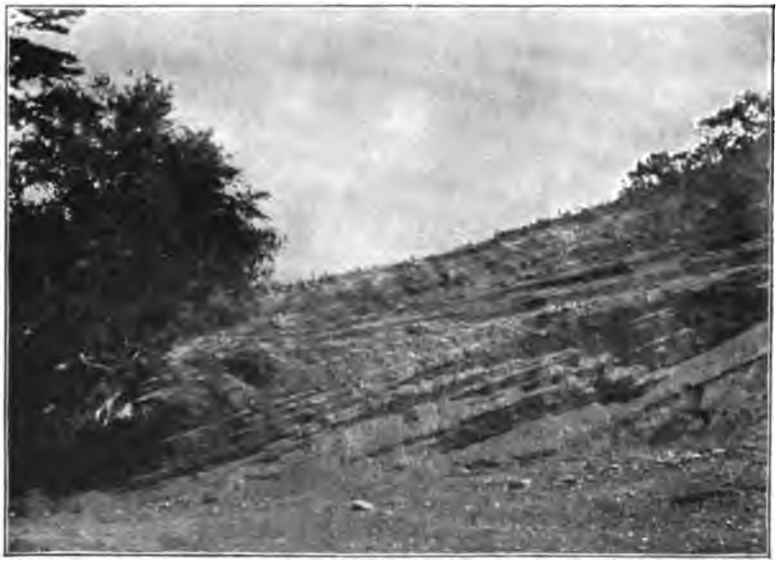

FIG. 60. Cross-bedded stratified drift, Ithaca, New York (photograph by C. S. Downes).

Held firmly in the ice, and dragged along beneath it, were rock fragments,—bits of clay, pebbles, and great boulders,—all journeying southward; and, side by side, were coarse and fine fragments. As the ice was withdrawing, and these rock fragments were loosened by melting, some of them went away in the water to be deposited as stratified drift; but much fell directly to the ground or stayed in its place at the bottom of the glacier. The drift thus deposited from the ice was not definitely assorted, but was made of clay, sand, pebbles and boulders mixed indiscriminately together, for the ice was able to carry a large boulder as well as a bit of clay, a fact which is not true of water under ordinary conditions. These deposits from the glacier form the characteristic soil of New York, particularly of the hillsides and hilltops, and, in places, of the valley bottoms also. This glacial soil is known as *till* or *boulder clay* (Fig. 35). Thus it happens that a farm in one part may be bouldery and clayey, in another part clayey without boulders, and still elsewhere either sand or gravel. In each of these cases there was a cause, which, by careful study, can often be determined, though sometimes this is impossible because of the complexity of conditions attending the withdrawal of the ice, the full evidence of which is sometimes lacking.

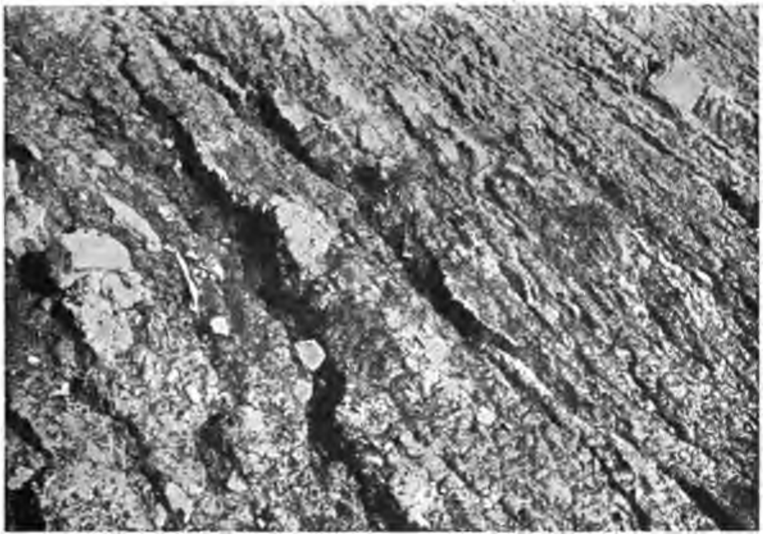

FIG. 61. Near view of a cut in glacial till, gullied by the rains and with numerous transported pebbles embedded in the rock flour.

With the withdrawal of the ice the conditions were again made favorable for the existence of animal and plant life upon the surface. Foot by foot the country was relieved of its ice blanket, and slowly the soil left by the glacier began to be made to nourish plant life and to furnish a dwelling place for animals. At first, skirting the ice front, there must have been strips of land entirely without vegetation. Then came the light-seeded grasses and small plants, and then the forest. During this bare condition of the soil the rain fell, and gathering into mud-laden rills, washed much of the imported soil away, as it now does on the roads and ploughed fields; and this sediment was added to the stratified drift from the glacier.

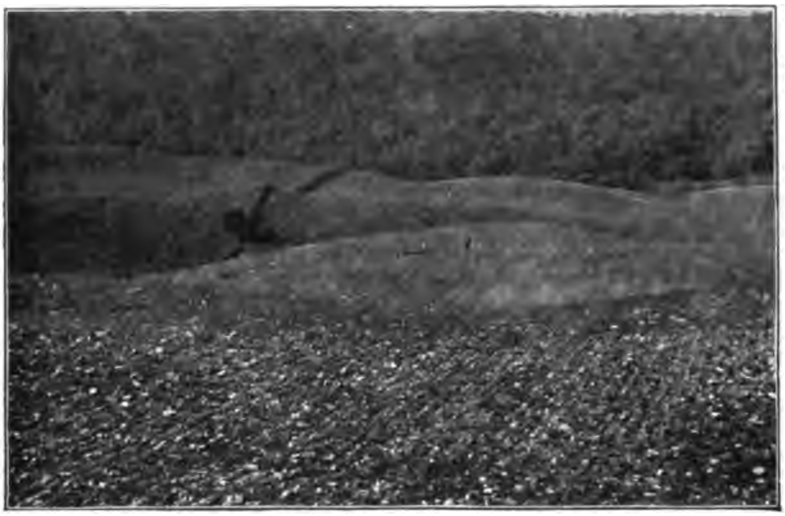

FIG. 62. The terminal moraine, West Danby, in Cayuga valley south of Ithaca, New York (photograph by C. S. Downes).

There is good reason to believe that the rains were perhaps heavier then than now, for the presence of the ice to chill the moisture-laden winds from the south, and the large amount of vapor that would be produced from the floods of the glacier-supplied waters, would bring about conditions favoring heavier rain. At this time, also, in places where the slope was sufficient for the removal of the sediment, the streams must have had more power to cut than now; and probably much of the gorge cutting in central New York was accomplished during this time,[1] when there was apparently more water and when the water that fell upon the surface certainly flowed away more quickly, in the form of floods, than it did later when its run-off was retarded by the forests. Also, at this time the streams had more sediment to serve as cutting tools than later, when the soil was held in place by the roots of the forest trees.

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[1] Tarr, Amer. Geol., XIX, 1897, 135.

What happened among the mountains during the *advance* of the glacier probably also happened during its withdrawal, though in reverse order. In Greenland the last stage of glacier retreat upon land from which the glacier has just withdrawn, is that of local valley glaciers. The same was true in New Hampshire, and Maine; and, no doubt, when studies of the Adirondacks have been made, evidence of local valley glaciation will be found there in many places.[1]

MORAINES.—*Topography.*—In many places where the ice front stood for only a very short time, the moraine which accumulated at the margin is not very deep. Sometimes it is merely a tract of unusually numerous boulders; but in many places so much material has been deposited that the moraine forms a very striking feature of the landscape. This is particularly true of many parts of the so-called terminal moraine of the Second Glacial Epoch.[2]

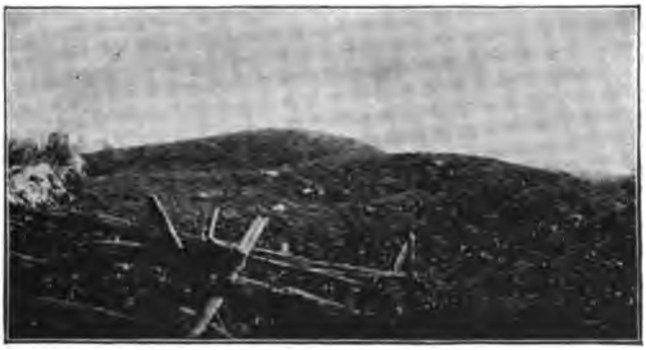

FIG. 63. Nearly boulder-free moraine in Pennsylvania (Lewis).

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[1] Since this was first written studies by the author in the Adirondacks have verified this statement of probability.

[2] Chamberlin, 3d Annual Rept. U. S. Geol. Survey, 1883, 291.

Among some of the moraines of recession to the north of this, as well as in the earlier Pennsylvania moraine to the south of it, the morainic topography is often strongly developed.

A terminal moraine is essentially complex, and this applies to both form and structure. In form, or topographic detail, it is typically a system of hummocky knolls, with intermediate valleys, often saucer- and kettle-shaped, forming distinct closed basins. The hummocks may reach to the dignity of good-sized hills, perhaps 200 or 300 feet high, though commonly not more than half this. Their form is often quite circular, sometimes elliptical, and again ridge-like. The hummocky hills are put together in such a confused manner that there seems to be no order whatsoever, the form being, on a much larger scale, somewhat the same as that produced when many loads of sand are dumped near together without any attempt at order. Some of the hummocks are steep, others gently sloping, some symmetrical, and others distinctly unsymmetrical. I know of no type of topography which closely simulates that of the moraine with the exception of the wind-blown sand deposits in a sand-dune region. In such places, judging from the form alone, one might often imagine

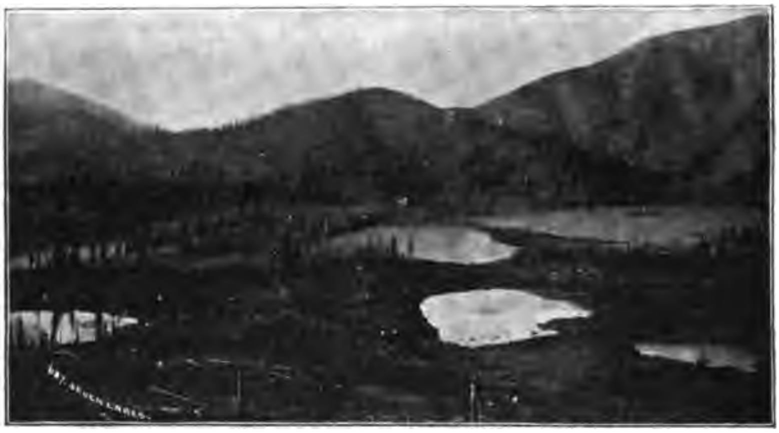

FIG. 64. Lake in kettle holes in moraine of Colorado Rockies (photograph by Jackson, Denver, Colorado).

himself upon a moraine. In a limestone region with abundant kettles there is also a certain resemblance to morainic topography.

The moraine is not a distinct ridge, but a range of low hills and valleys, with a breadth from north to south of rarely more than two or three miles, though sometimes, as in the southern end of the valleys of the larger Finger Lakes of New York, from ten to fifteen miles in a north-south direction. When seen in a near view, the moraine exhibits a striking topography; but when looked at as part of a general hilly region, its importance becomes greatly masked,[1] because of the lowness of the hummocks. Indeed, many moraines in hilly districts have not yet been detected because of this very fact.

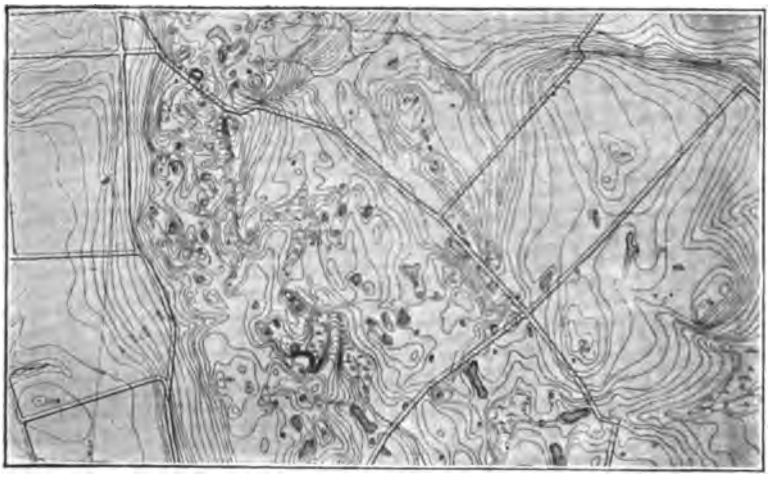

Fig. 65. A part of the New Jersey moraine showing (by shading) numerous kettle ponds (Salisbury).

Next in importance to the hummocks are the valleys, which are often true basins called *kettle holes*. In places these are so prominent that the moraine has been called a kettle moraine.[2] In these basins there is often no water,

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[1] See Fig. 41, where a very pronounced moraine, occupying nearly the entire valley south of Lake Cayuga, is masked by the general topographic features.

[2] Chamberlin, Trans. Wisconsin Acad. Sci. IV, 1876–77, 201.

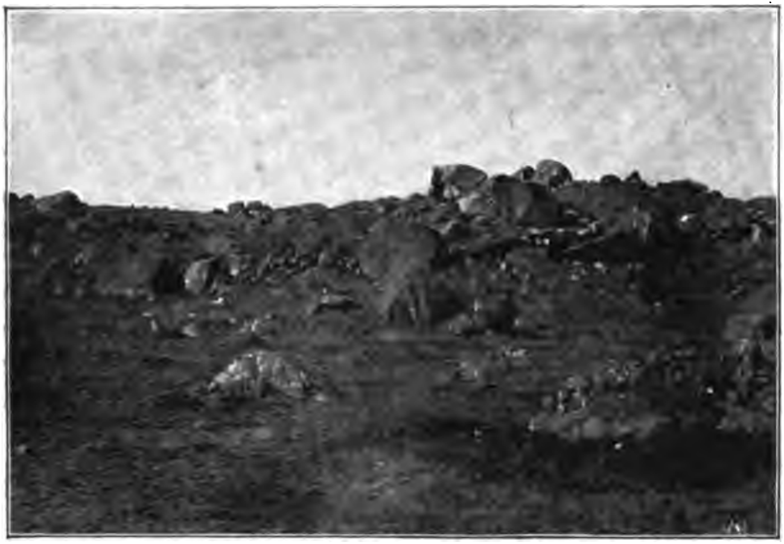

Fig. 66. The bouldery Cape Ann (Massachusetts) moraine (photograph by J. L. Gardner, 2nd).

because the bottom is too porous and the water supply too slight, coming merely from the rim of the tiny basin; but where the drainage area is larger, or the bed more impervious, a kettle is often transformed to a pond or swamp. Indeed, in some places there are so many that the moraine is literally dotted with tiny morainic ponds (Fig. 65). The depth of these kettles varies greatly, some mentioned by Koons being 50–90 feet deep.[1] These basin-like depressions are sometimes circular or elliptical or irregular, apparently being formed irregularly, as were the hills. Indeed, in many cases the kettles are merely the spaces where morainic deposits were not made.

Structure.— The internal structure of the moraine is also exceedingly complex. As in the case of the till sheet, it is sometimes almost free from boulders, sometimes exceedingly bouldery. In New York, the moraine is commonly rather free from large stones, as is the till sheet also, the reason for this being that the rocks of the State are prevailingly soft and easily ground down. This is particularly true of central and western New York, where the scattered large boulders are mostly Canadian in origin; but in many sections, as in eastern New York, there are places where boulders are more common, because of the greater hardness of the rock of the neighborhood and immediately to the north. In New England the prevailing condition of the till is bouldery, for the same reason.

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[1] Koons, Amer. Journ. Sci. Ser. III, XXVII, 1884, 260–264; same, Ser. III, XXIX, 1885, 480–486.

When a morainic hummock is cut into and its internal structure revealed, it may be found to be till throughout, or it may be entirely made of gravel, or there may be a certain proportion of each of these. There is a complexity of structure which is most confusing; and one can see no law in the distribution of materials. Some moraines are prevailingly sand and gravel, others prevailingly till. One can rarely tell what will be found when a morainic hummock is cut through. There may be all till or no till, all stratified clay or none of this, all sand and gravel or none; or some of each of these deposits may occur.

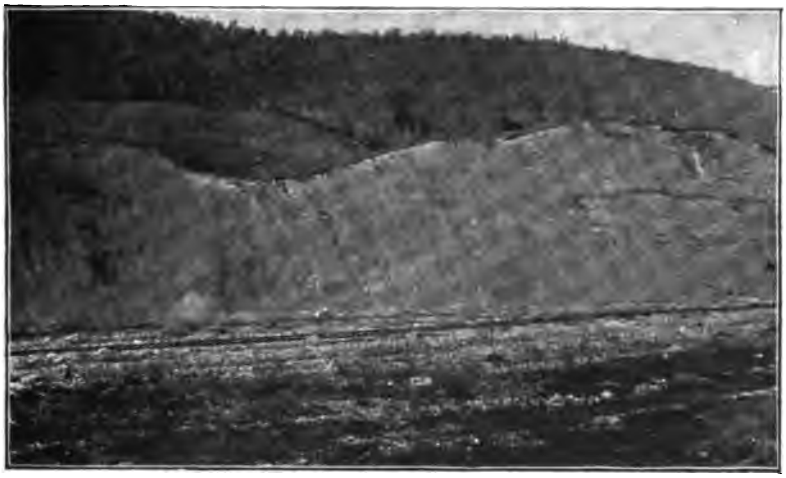

FIG. 67. Section through a part of the moraine in Cayuga valley south of Ithaca, showing stratified drift on right and unstratified till on left (photograph by C. S. Downes).

Sometimes beds of sand or gravel are found upon till; again, they occur beneath the till, or possibly sandwiched between two till beds.

Explanation of Morainic Irregularities.—There must be a cause for this variety of form and structure. In any specific case it would be exceedingly difficult to find the cause for each of the hills and kettles; and indeed the explanation of these irregularities is not agreed upon even in general terms. Professor Salisbury[1] considers moraines to be chiefly the result of accumulations of drift *under* the frontal edge of the ice, to which place it has been dragged and there left, because near the thinner ice edge it was impossible to carry the drift load further southward. To this cause was of course added that material which was dumped from the ice-front as it melted, as well as some that was pushed or "shoved" up to the margin by ice advance; but these two last causes are believed to be subordinate. Other glacialists assign to the dumping process the chief importance, and still others believe that shoving has been of most importance. In fact, Professor Shaler[2] speaks of the "shoved moraine" as a synonym for a part of the terminal moraine.

This is not the place for a discussion of the merits of this question. It seems very probable that, at different times, or in different places, as the circumstances varied, either of these causes may have predominated. My own conception of how a moraine is built is that the dumping predominates in the main, with shoving of secondary importance, while submarginal accumulation is more rarely of prime importance. This is based partly on my own conception of ice work, partly upon a somewhat wide-extended view of the terminal moraine of the eastern part of this country, and partly upon a study of the extensive moraine now forming in Greenland along a part of the margin of the great continental glacier. The statement that follows is therefore advanced purely as my own conception, and not necessarily that of others. It is recognized that very likely in the Middle West, where the ice load was greater, submarginal accumulation may have been much more important than it seems to have been in the east, and vastly more important than it *is* in Greenland.

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[1] Annual Rept. New Jersey Geol. Survey, 1891, 81.

[2] Ninth Annual Rept. U. S. Geol. Survey, 546.

The ice carried a greater amount of débris to some places than to others, partly because it actually had more material to carry, and partly because it was moving faster in some places than in others. This is one element of irregularity. Here and there such a difference in supply may express itself in morainic accumulations *under* the margin of the ice; but wherever I have carefully studied the moraine there has been found no evidence that this was so. In Greenland, and apparently also in New York and New England, the chief moraine supply seems to have been from the ice front. As living glaciers, while holding a general position, vary their exact ice front with the season, so the continental glacier, while building its moraine, advanced and receded during its general stand. Hence material previously deposited at the glacier front would be overridden, and perhaps shoved up into ridge-like hills; or, if the ice withdrew, new areas would be opened to the process of dumping.

All of this time the ice is moving up to the end, bearing its load, which, when the ice melts, slides down to the base in the form of pieces varying from bits of clay to large boulders, more perhaps coming to some places than to others. This process may be actually seen in operation in Greenland to-day (Figs. 55 and 57). If the ice advances, overriding, or possibly even shoving some of the moraine in front of it, the deposits are heaped up even more irregularly than by the first dumping. That something of this sort has happened is indicated by the fact that in the moraine the strata are often tilted and broken, showing that they have been subjected to some force.

Hills and valleys are formed as the ice front changes its line of deposit. This is the cause for the hummocky topography in the Greenland picture (Fig. 57), and seems perfectly competent to explain the similar irregularities in the United States. In fact, until proof is brought to the contrary, I feel that this view of the origin of many of the moraines stands best supported by fact.

The irregularity of form described above, as well as the irregularity of texture, is greatly increased by the action of water from the ice. In some cases the moraine is being built upon a hillside sloping away from the ice, and then the water may remove much that the ice brings; but if the opposite is true, very little escapes, so that, with the same rate and amount of till supply, we may have great or small moraines built according to the proportion carried away by the water. This cause for irregularity applies equally in a small way. Here a stream was cutting a hummock away; there it was depositing a part of the material already removed, perhaps in little marginal lakes extending along the ice front. In consequence, the conditions were exceedingly complex, so that, naturally, the results were complex both as to structure and form. This complexity of conditions may be observed along the Greenland ice margin at present and probably also existed in the United States during the ice age.

While advocating this view, it is not insisted that submarginal accumulation is impossible, nor are the three causes above mentioned *all* that were possible. The surface of the ice may have become covered with rock débris, like that to be seen in the Malaspina Glacier of to-day; and this, through irregularity of melting of the ice which the débris covered, may have assumed distinctly morainic form and structure, and then, as the ice melted, have been dropped to the ground and added to the other accumulations. Again, débris washed from the land to the ice margin, or even out upon it, may have helped make the moraine. Such an origin is indicated for a part of the moraine in the Lake Cayuga valley, and apparently accounts, in part, for its remarkable development in that valley, while elsewhere along the same morainic line the moraine topography is for the most part especially marked only in the valleys, and is sometimes almost indistinguishable.

The Extent of the Moraine in New York.—No attempt will be made here to tell in detail about the distribution of the New York moraines. What little is known is mostly told upon the accompanying maps (Figs. 48, 58 and 59); but it is to be understood that the Chamberlin map is merely an approximate and generalized expression of the principal morainic districts. Numerous moraines are not placed upon it, and those that are, are not always correctly placed. It was based upon a preliminary reconnaissance, and, unfortunately, nothing of a more thorough nature has since been done in the greater part of the State.

A few words of a general kind may accompany these maps. It will be noticed that the moraine enters New York from the southwest, just to the southwest of the lower end of Chautauqua Lake. At Jamestown it is remarkably well developed, and, from that point, two lines of moraine diverge, one passing northeastward toward the western boundary of the Genesee Valley, the other passing very near Salamanca southeastward into Pennsylvania, and thence on to New Jersey.[1] With the interpretation of Lewis and Wright, that the southernmost moraine is in reality the outermost moraine of the last glacial advance, I am in full agreement. The facts presented by these writers have never been satisfactorily disproved. Therefore, notwithstanding the difference of opinion expressed upon Prof. Chamberlin's map, I accept the interpretation of the Pennsylvania geologists.

According to this view the actual terminal moraine is found in only two parts of New York State, the Long Island region and southwestern New York, which is the place where the ice front stood farthest north in eastern United States. The reason why the glacier did not reach farther south in western New York is partly the barrier caused by the very high plateau region of rugged topography which exists in northern Pennsylvania and southwestern New York. Where the terminal moraine of Lewis and Wright crosses central New Jersey it is well developed and the same is true where it again enters the State of New York in New York Bay, where it crosses to Long Island. The sandy and hummocky hills of this island are in large part due to the remarkable development of the terminal moraine,[1] which may be traced still further eastward upon Block Island, the Elizabeth Islands, Martha's Vineyard and Nantucket. It is by no means certain that the Long Island moraine is the actual outermost terminal moraine, for it is possible that the ice front to the south of New England was at one time in the sea to the southward of Long Island. In that case the Long Island moraine may correspond with one of the later halts, possibly with the well developed one in west central New York. Much careful work is necessary before the exact correlation of the several moraines is possible.

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[1] This moraine is the one described by Lewis and Wright. See reference, page 113.

North of this extreme terminal moraine are numerous morainic patches and somewhat indistinct lines of morainic topography, many of which are not yet mapped and correlated. There is, for example, some moraine in the valley of the Chemung and Susquehanna Rivers, as well as in some of their tributaries, indicating a series of brief halts of the ice. Still further north, in the Genesee Valley, and along the headwater region of the Finger Lakes, and thence northeastward to the Mohawk, there is much moraine, indicating a prolonged halt of the ice, with the front by no means uniform in position. The history marked by this development of moraine has never been worked out, though it is not so simple as might be supposed from the map (Fig. 58). There were numerous minor halts and fluctuations of position in the general stand in this vicinity. This moraine is strongly developed, but from the valleys alone one would get an erroneous notion of its importance. There are places on the hills where this moraine, though strongly developed in the valleys, is traced with difficulty. The detailed work of Leverett,[1] indicated by Figure 59, gives some idea of the complexity of the ice withdrawal from western New York.

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[1] Bryson, Geol. Mag., X, 1883, 169–171; Amer. Geol. III, 1889, 214; same, XII, 1893, 127, 402; same, XIII, 1894, 390; same, XV, 1895, 188; same, XVI, 1895, 288; Dana, Amer. Journ. Sci. Ser. III, XL, 1890, 425–437; same, Ser. III, XLI, 1891, 161; Hollick, Trans. New York Acad. Sci. XII, 1893, 189–202, 222–237; same, XIII, 1895, 122–130; same, XIV, 1894, 8–20; same, XV, 1895, 3–10; same, XVI, 1896, 9–18; Lewis, Amer. Journ. Sci. Ser. III, XIII, 1877, 142–146; Mather, New York Geol. Survey, 1st Dist. 1843, 271; Merrill, Ann. New York Acad. Sci. III, 1883–5, 341–364; Upham, Amer. Journ. Sci. Ser. III, XVIII, 1879, 81–92, 197–209.

North of this well developed morainic band there are others, the best developed one in New York being north of the Finger Lakes, and not shown on the Chamberlin map. In the Adirondack region there are other moraines of recession.[2] Concerning the moraines of the Adirondacks, the Catskills, and other sections of eastern New York, practically nothing is known.[3] There certainly are moraines in this region, as there are in New England; and in all probability the recession of the ice from this section of the State was much more complex than in the central and western portions; for, in addition to the moraines made by the great ice sheet, very much influenced by the rugged topography, and hence scattered and difficult to trace, there were local glaciers in the mountain valleys, as there are now in Greenland, and as there were at the close of the Glacial Period in New Hampshire and Maine. The mapping and correlation of these moraines is one of the important problems in the geology of New York and one that will help greatly in interpreting the history of the glacial period. Until such work has been done in New England and New York we will have but a meagre knowledge of the great American ice sheet.

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[1] Amer. Journ. Sci. Ser. III, L., 1895, 1-20.

[2] For an interpretation of the withdrawal of the ice front from North America, see Upham, Amer. Journ. Sci. Ser. III, XLIX, 1895, 1-18; Bull. Geol. Soc. Amer. VII, 1896, 23; Chalmers, Amer. Journ. Sci. Ser. III. XLIX, 1895, 273-275.

[3] Some notes on Glacial Geology of New York will be found in the following: Dana, Amer. Journ. Sci. Ser. II, XXXV, 1863, 243-9; Stevens, Amer. Journ. Sci. Ser. III, IV, 1872, 88-90; Julien, Trans. New York Acad. Sci. III, 1883, 22-30; Brigham, Amer. Journ. Sci. Ser. III, XLIX, 1895, 213-228.

OVERWASH PLAINS AND VALLEY TRAINS.[1] — These have already been mentioned (pp. 86–88) and can therefore be briefly dismissed here. Where the glacier front stood for a long enough time to build morainic hills, the floods of water, being commonly overburdened with sediment, built up deposits of stratified gravel on the southern side of the moraine (Figs. 36 and 68). Where the topography was not rugged, numerous ice-derived streams built sloping plains resembling low alluvial fans. These are well seen on Long Island and Martha's Vineyard, and to those of the latter place Professor Shaler has given the very descriptive name of *frontal aprons*.[2] The plains on the southern slope of Long Island are of this origin, and they are often crossed by the channels of the streams that built them, though now in many cases no water flows in them.[3] Overwash plains, as these are also called, are not confined to this section, but in less perfect development are found every here and there on the southern side of the New York moraine, particularly in the south-sloping valleys (Fig. 68). The best instance with which I am familiar outside of Long Island is that upon which Horseheads, north of Elmira, is situated.[4]

These plains often merge into valley trains of stratified drift. Practically all the south-sloping valleys of western New York have been embarrassed by these sediments,[5] which are sometimes very deep. The Susquehanna and its tributaries, even beyond the boundary of New York, contain deposits of this origin, so that now the river, as in the case of many others, is flowing high above the old rock bottom of the pre-glacial valley. By this water action much of the glacial drift was removed well beyond the ice margin, and not a little of it reached the sea. The stream valleys sloping away from the ice all show some effects of this flooding with sediment-laden glacier water.

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[1] See Salisbury, 1892 Report, New Jersey Geol. Survey, 96–125.

[2] Shaler, 9th Annual Report, U. S. Geol. Survey, 1889, 548.

[3] See references (on p. 128) to the Long Island moraine.

[4] Fairchild, Bull. Geol. Soc. Amer., VI, 1895, 367.

[5] Brigham, Bull. Geol. Soc. Amer., VIII, 1897, 17–30.

These deposits grow finer and finer as we proceed downstream, being coarse gravel near the moraines and oftentimes fine clay near the sea.

The surface of overwash plains, valley trains, moraines and sandplains (described just below) is often pitted with little kettle-shaped depressions.[1] These kettles were sometimes caused by irregularities of deposits, either through differences in supply of material, or through the influence of currents which were swirling about, forming eddies here and there. In other cases, and perhaps the majority, the kettle has resulted from failure to deposit material because that particular part of the surface was occupied by an ice fragment or a stranded iceberg. By the deposit of stratified drift all around the stranded ice fragment and finally over it, and then by the ice melting, the sediment was left to settle down, forming a kettle-hole. In the marginal lakes on the coast of Greenland instances of the latter origin of kettles may be seen; and it is probable that while the American ice sheet was melting away, the conditions favoring this mode of formation of basins were in operation.

LAKE DEPOSITS.—During the retreat of the glacier, as is shown on page 111, many lakes were made in regions where now they are impossible. At that time there were ice dams where at present there is no barrier to the free northward flow of the rivers. As the ice front withdrew, passing north of the Allegany and Susquehanna-St. Lawrence divide, each of the valleys that sloped northward was dammed by the glacier, and lakes were formed in their southern ends. The areas of these lakes grew as the glacier front stood farther and farther north, until, finally, the ice-withdrawal was sufficient to admit of a northern outflow, when the lake level fell. This distinct lake history by itself has been interesting, and is told by the deposits made during the time that the waters were thus ponded.[2]

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[1] See references to Koons, p. 122; also Woodworth, Amer. Geol., XII, 1893, 279.

[2] Fairchild, Bull. Geol. Soc. Amer., VI, 1895, 353–374; Lincoln, New York State Museum Report, 48, Part 2, 1894. 74–77; Watson, New York State Museum Report, 51, Part 1, 1897, r55–r117.

Along these lake shores, beaches and bars were in some cases built, while deltas were very commonly formed at the mouths of the tributary streams. These, however, are not strictly glacial deposits, though in cause intimately related to the glacier. But in the lakes, deposits of stratified drift were also made from material derived directly from the ice. As the streams emerged from the glacier into these temporary lakes, they poured their volumes of sediment into the quiet lake waters, where it settled, the coarsest near the glacier, the finer farther away, forming a layer of lake clay. Such clay deposits are especially well developed along the southern shores of Lakes Erie and Ontario, though not absent from the numerous smaller valleys of the Finger Lake region. To these were added deposits dropped from the glacier itself, and still others that were floated away into the lake, buoyed up by the tiny icebergs that must have broken from the ice front.

These deposits have not notably modified the surface of New York, though they have added somewhat to the glacial modifications of the details of topography. Along the ice margin, at its various stands, deposits must have been made rather extensively near the mouths of the sub-glacial rivers. No doubt such deposits are common in portions of the State, though they have not been described from there. In New England they are quite commonly found, especially near the coast, where they are called *sandplains*.[1] These are really deltas in a body of water now absent. The material was supplied from the melting of the ice, and the form of the deposit is that of a true delta, flat-topped, with steep front, and traversed by stream channels, and sometimes pitted on the surface by kettles, probably formed by the same means as those mentioned above (p. 130).[2] Future study will no doubt discover sandplains in New York (p. 90).

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[1] There is reason for believing that some of the New England sandplains are really deltas formed in the sea when the land was somewhat lower than at present, as it was during the close of the Glacial Period.

[2] For a discussion of sandplains see Davis, Bull. Geol. Soc. Amer., I, 1890, 195–202; Davis, Proc. Boston Soc. Nat. Hist., XXV, 1892, 477–499; Gulliver, Journ. Geol., I, 1893, 803–812; Salisbury, Annual Rept. New Jersey Geol. Survey, 1892, 99–102.

KAMES.—Throughout New York, commonly in association with the moraines, but often isolated, there are single hills, or groups of hummocky hills, of stratified drift called *kames*.[1] In topographic form they resemble moraines and are often a part of such deposits; but elsewhere they seem to bear no relation to morainic bands. Single hummocks may be found upon hillsides and even on hilltops. They are well stratified, sometimes confused with the layers dipping in various directions, and exceedingly variable in texture. Moreover, the layers are sometimes broken, showing disturbance subsequent to deposit. In different places their origin is apparently quite different. Glacial water has evidently made them; but there are various ways in which this water may construct hills of stratified drift. Deposits in caverns under the ice; hills made by cascades which carried much sediment down the ice front or through crevasses into the ice; deposits in tiny lakes upon the surface of the glacier; and the escape of subglacial streams into marginal lakes, are some of the more common ways in which kames may have been made. By such action hills several scores of feet in height have been constructed.

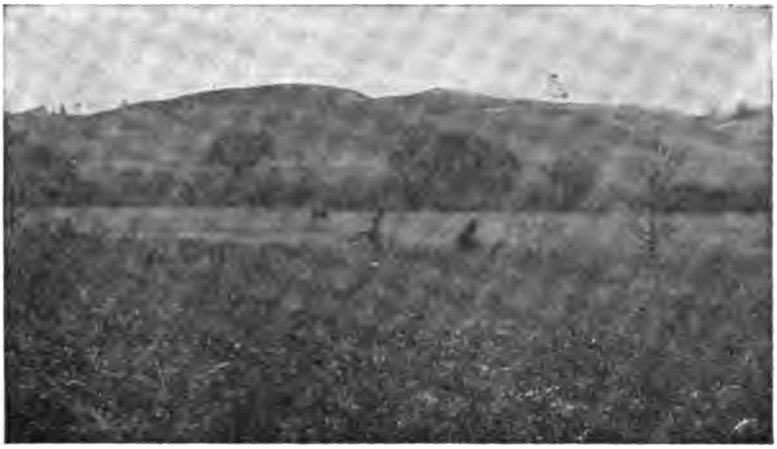

FIG. 68. A group of kame hills with deep kettles in the moraine near Freeville, New York. An overwash plain is seen in the foreground.

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[1] Salisbury, Annual Rept. New Jersey Geol. Survey, 1891, 92–95; same, 1892, 84–95.

Naturally the conditions favoring such deposits will exist only near or at the ice margin; but as this front was in all parts of the State at different times, kames may be found in any part of New York; and indeed they do occur all over the State, sometimes rising in what appear to be the most unnatural positions. Where the ice stood longest they would be most abundant; and hence they are most common in association with the moraines. Slight forward movements of the ice and settling of the material would break and disturb the layers as we find them. Few specific cases of kames have been described in New York,[1] but they are known here and have also been described from various parts of the country.[2]

ESKERS OR SERPENT KAMES (OSARS).— Ridges of gravel bearing a close resemblance to embankments are frequently found within the glaciated area. In these the material is usually coarse. Sometimes the eskers are made of good-sized and well-rounded pebbles, oftentimes several pounds in weight. In other cases, however, eskers are made almost entirely of sand. The stratification, while often noticeable, is usually somewhat confused, and the ridge may be coarse in one place and much finer in another.

In the form of eskers there is much variation. Typically they are distinct, narrow-topped ridges, extending in a more or less irregular or serpentine course. Some are mere low banks; others have a height of several scores of feet. In some cases the crest of the ridge is level; but more commonly it undulates somewhat and has a gradual slope in one direction, normally sloping downward in the direction of ice movement as revealed by the striæ upon the bed rock. Variations from this normal form are common. At times the ridge is interrupted, and it may end abruptly, or even very gradually, often terminating in a broad, sandy area. Some eskers end in sandplains;[1] and they may even end in a tiny valley cut in the till.

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[1] See particularly Fairchild, Amer. Geol., XVI, 1895, 39–51; Journ. Geol. IV, 1896, 129–159; Brigham, Bull. Geol. Soc. Amer., VIII, 1897, 17–30; Lincoln, New York State Museum Report, 48, Part 2, 1894, 72–74.

[2] For instance, see Upham, Hitchcock's Geol. of New Hampshire, Vol. III, 1878, 12–176; Lewis, Second Geol. Survey Pennsylvania Report Z, 1884, 35–36; 61–65; 78–81; 100–111, etc.; Chamberlin, Journ. of Geol., I, 1893, 255–267.

As for location, eskers may be found anywhere within the glacial belt, though they are more common near the moraines. They are very abundant in eastern New England, and have been well described for the Boston region.[2] Among the mountains of Maine[3] and New Hampshire[4] they are common. The term esker is an Irish name,[5] and these peculiar ridges are common in Ireland, as elsewhere in the British Isles[6] and northwestern Europe. In Scandinavia they are called äsar (anglicized osars). Little

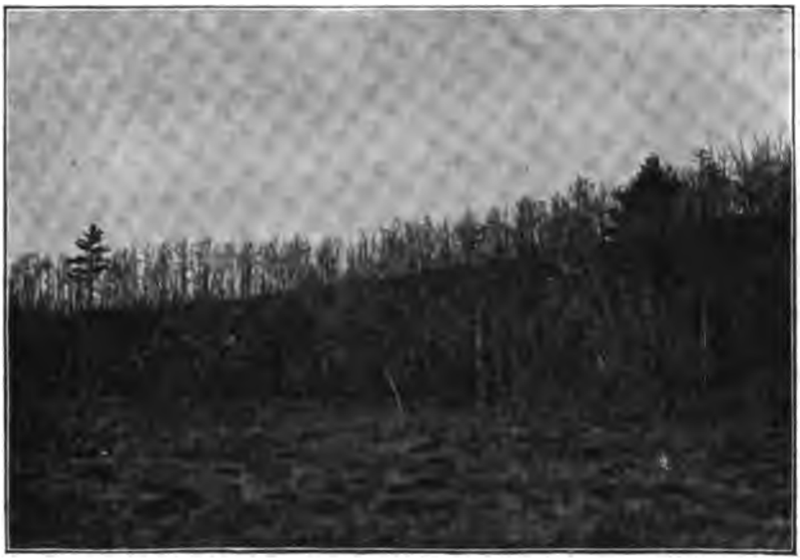

FIG. 69. Side view of an esker at Auburndale, Massachusetts (photograph by John Ritchie, Jr.).

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[1] See Davis, Bull. Geol. Soc. Amer., I, 1890, 195–202; Davis, Proc. Boston Soc. Nat. Hist., XXV, 1892, 477–499; and Gulliver, Journ. Geol., I, 1893, 803–812.

[2] Bouvé, Proc. Boston Soc. Nat. Hist., XXV, 1891-92, 173–182.

[3] Jackson, Geol. of Maine, 1st Rept., 1837, 64; Stone, Proc. Amer. Asso. Adv. Sci., XXIX, 1880, 510–19; Monog., XXXIV, U. S. Geol. Survey, 1899.

[4] Upham, Hitchcock's Geol. of New Hampshire, Vol. III, 1878, 12–176. For New Jersey eskers, see Salisbury, 1892 Report New Jersey Geol. Survey, 79–83.

[5] Young, Report British Assoc., XXII, Part 2, 1852, 63–64; Kinahan, Amer. Journ. Sci., Ser. III, XXXIII, 1887, 276–278.

[6] Home, Report British Assoc., XXXI, Part 2, 1861, 115–6.

work has been done upon the eskers of New York, though they occur in association with the moraine.[1] Instances of eskers may be seen near Freeville, New York, and along the Lehigh Valley Railway west of Geneva. In all probability they are common, particularly in the more hilly sections, such as the Adirondacks.

As for the details of location, eskers are very commonly found in valleys, but are by no means confined to them. They have been found upon hillsides and are known to cross valleys, extending down one side and up the other.[2] Such conditions are exceptional, and the type location may be said to be the valley, or else the immediate neighborhood of a moraine. In such positions they may be but a few score of yards long or may extend for miles. Some of the eskers of Maine are exceedingly long and well defined. When typically developed they

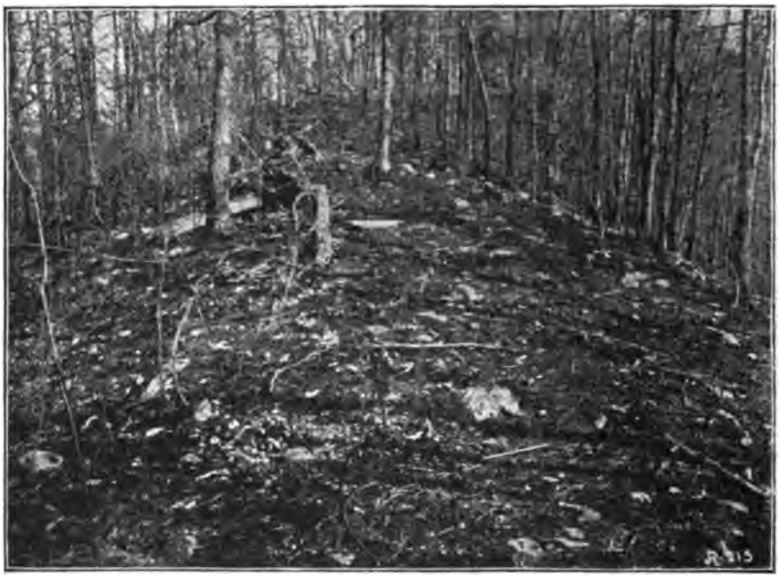

FIG. 70. Crest of an esker at Auburndale, Massachusetts (photograph by John Ritchie, Jr.)

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[1] Upham, Proc. Rochester Acad. Sci., II, 1893, 181-200; Fairchild, Journ. Geol., IV, 1896, 129-159.

[2] Shaler, Ninth Annual Report U. S. Geol. Survey, 549.

have a remarkably artificial appearance, sometimes closely resembling an abandoned railway embankment. They have in some cases been explored in the belief that they were Indian mounds.

The form and characteristics of eskers point plainly to stream origin and to the conclusion that they are really the beds of glacial streams. There has been some question whether these glacial stream beds were formed under the ice (subglacial) or in the ice (englacial), or upon the ice (superglacial), and this question is still an open one.[1] The facts seen in living glaciers,[2] and those discovered by the study of existing esker deposits, point to a subglacial river origin as by far the most probable,[3] although other facts brought forward seem to show that there are *some* eskers which have been formed by superglacial or possibly even englacial streams.[4]

Near the ice front streams were flowing in each of these positions, but by far the greater amount of drainage near the ice terminus must have been subglacial. In either case the running water was supplied with much sediment which was being dragged along the stream bed. Wherever more was given than the stream could remove, deposits were necessarily made in the stream bed. Since the ice contained many pebbles and boulders, as well as finer clay, it would not uncommonly happen that the stream could not remove as much sediment as was given to it. Then, at the bottom of the ice canyon, an embankment of gravel would be built, held in by ice walls, and resting either upon the ice (in englacial or superglacial valleys), or, if subglacial, on the ground. When the ice withdrew, the stream deposits would settle, the sides taking the slope of gravel at rest,[1] but retaining the average slope of the stream bed (if this were on the ground) and its meandering direction. Therefore the esker represents a fossil glacial stream bed, whether subglacial or superglacial or englacial.

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[1] Davis, Proc. Boston Soc. Nat. Hist., XXV, 1890-92, 477-499; Chamberlin, Journ. of Geol. I, 1893, 255-267; Upham, Bull. Geol. Soc. Amer., V, 1894, 71-84; Amer. Geol., XIV, 1894, 403-405; Winchell, Amer. Journ. Sci. XXI, 1881, 358-60; Sollas, Report British Assoc., 1893, 63, 777; Russell, Amer. Journ. Sci. Ser. III, XLIII, 1892, 178-182; Thirteenth Annual Rept. U. S. Geol. Survey, Part II, 81-82; Reid, Sixteenth Annual Rept. U. S. Geol. Survey, Part I, 442.

[2] Russell, Amer. Journ. Sci. Ser. III, XLIII, 1892, 178-182; Thirteenth Annual Report U. S. Geol. Survey, Part II, 81-82; Reid, Sixteenth Annual Report U. S. Geol. Survey, Part I, 442.

[3] Davis, Proc. Boston Soc. Nat. Hist., XXV, 1890-92, 477-499; Chamberlin, Journ. Geol. I, 1893, 255-267.

[4] Winchell, Amer. Journ. Sci. XXI, 1881, 358-60; Upham, Bull. Geol. Soc. Amer., V, 1894, 71-84; Amer. Geol. XIV, 1894, 403-405.

The confused stratification is due to the irregularity of deposit, later settling, and possibly to disturbances caused by ice movement. The frequent interruption of form may be due to ice movement or to failure to deposit in particular places; and the broadening out occasionally noticed, from the ridge slope to the low sandy areas, may represent the terminus of the esker stream, either at the glacier margin, or in some broad part of its ice-walled valley. The location of eskers upon hillsides may be easily accounted for. If formed on or in the ice, the exact location is essentially accidental; and when the ice disappears the eskers may as well settle upon the hillsides as in the valleys. If, on the other hand, as seems much more commonly, if not almost universally, to be the case, the esker stream was subglacial, the water that was building the esker was flowing in an ice channel under considerable pressure, so that it might even flow up hill, if the hill were not higher than the pressure head, for the same reason that water rises through pipes to the second story of our houses. But while water *could* be forced over hills in subglacial tunnels, the location of these tunnels would most commonly be in the valleys.

THE TILL SHEET.—The material that was on, in, or under the ice (superglacial, englacial and subglacial till) at the time it melted away from any given place, was left upon the surface of the country as a till sheet, that part removed by water being of course excepted. This till sheet, which covers the greater part of New York, and particularly the hillsides and hilltops, varies greatly in character from place to place. Typically and prevailingly it is a *boulder clay* (35 and 61), which, as the name suggests, is essentially a boulder-bearing clay. The percentage of boulders varies from nearly boulder-free to a class of till in which more than one-half the mass is made of boulders (Figs. 71 and 72). The clay is a *rock flour* made by the grinding of the rocks as they are dragged along by the ice; and this abrasion is further indicated by the fact that many of the boulders and pebbles are grooved and polished.

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[1] Woodworth, Proc. Boston Soc. Nat. Hist., XXVI, 1895, 197–220.

The color of the till sheet varies greatly, depending in large measure upon the color of the rocks over which the ice passed just before it was deposited. This indicates a rather local origin for much of the till; and such an origin is still further suggested by the fact that among the boulders are found many of local origin. Still, in a region where the rocks are soft, as they are in the shale country of central New York, the local rock fragments are worn so rapidly that large pebbles of them may be less numerous than Canadian boulders and pebbles, which, though brought from afar, being harder, have been better

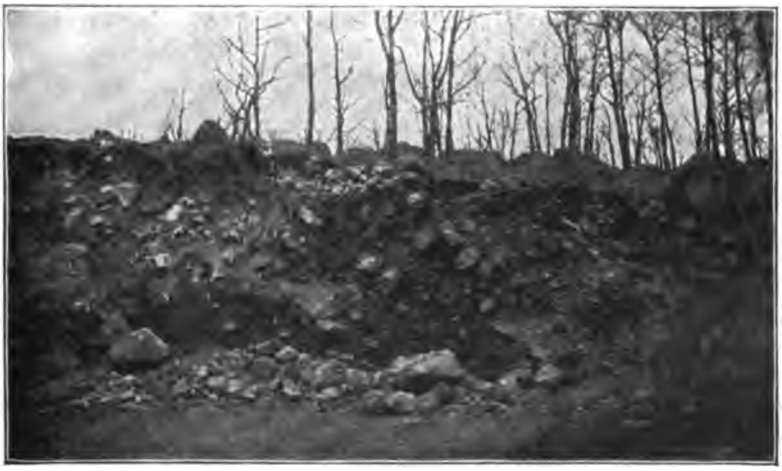

FIG. 71. Section in very bouldery morainic till, Cape Ann, Massachusetts (photograph by J. L. Gardner, 2d).

able to survive a long journey than the shale fragments were the much shorter one. The farmers have practically asserted this fact when they have called these foreign boulders, resting in the midst of soft shale strata, by the very descriptive name of "hardheads." In the region from which the hardheads have come, boulders may be so common that, as in parts of New England, the soil is almost incapable of cultivation (Figs. 71 and 72).

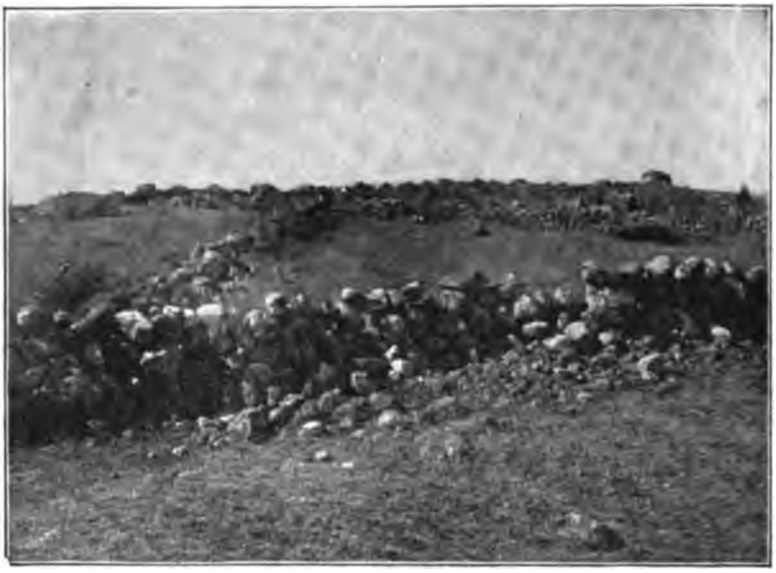

FIG. 72. Boulder-strewn surface of morainic till, Cape Ann, Massachusetts (photograph by J. L. Gardner, 2d).

While the color of the drift is variable, its usual color, when fresh and unoxidized, is blue, grading to a yellow near the surface, where it is stained with the limonitic iron stain that has been formed by the oxidation of iron-bearing minerals. The blue color is due to the finely comminuted and undecayed rock particles, and may be present even when the till has been derived from light-colored gneissic and granitic rocks

Although typically a clay, the till is sometimes sandy, though not commonly. When very clayey it is often so compact that it is difficult to dig through it with a spade.

Such compact clay has been given the name of "hard pan," and it owes its compactness not merely to the fineness of the clay, but also, at times, to the fact that it has been pressed into a compact condition by the weight of the ice which once rested upon it.

The mode of origin of the till sheet was, first, the removal of loose fragments from the surface, then, with the aid of these, the grinding off of others, accompanied by the grinding of the various particles into finer bits. In position, while some of the fragments may have been upon the ice top, and some within the ice, the greater part was dragged along either just beneath the glacier or frozen in its lower layers. In Greenland the latter is the common mode of transportation of the débris load. That glacier has a smaller burden of rock fragments than the American glacier had, and the till sheet which it is depositing is, therefore, much less developed. There is good reason for believing that some of the American till was dragged along beneath the ice, so that in this case, as in some other respects, the Greenland glacier of to-day is not a fair guide for conditions prevailing in America during the Glacial Period.

With the retreat of the glacier, the rock load, wherever carried, was left upon the surface of the land. In examining the surface of a large area, like that of New York, we find that the till sheet varies greatly in depth. There are places where there is almost none except in the little depressions, and this is particularly the case among the high gneissic peaks of New England and the Adirondacks. This means either that none was deposited or else that it has been removed; and sometimes one explanation is correct, sometimes the other, as in Greenland, where the original till deposit was slight and the land slopes are so great that much of that deposited has been carried off. Frequently the till sheet is but a few inches or feet in depth, and then the rock is reached in ordinary trenches. This condition is most common upon hilltops or upon those hillsides where we may believe the ice movement to have been relatively rapid. In such places little was left, because little was held under the ice, the movement being rapid enough to prevent such accumulations, somewhat as a river with rapid flow, during time of flood, can clear its bed of the gravel bars that were accumulated at some time of less rapid movement.

The thickness of the till sheet varies progressively also over wide areas. As a general statement, subject to many local modifications, the till sheet of New England and eastern New York is thinner than that of western New York, and this is thinner than that of the Central States, where it is sometimes two or three hundred feet deep.[1] This general change in thickness is parallel with a change in topography from mountain to hill and then to plain. In the Central States the ice slope was slight and the ice current probably less rapid than in the more irregular regions of the east. The variation is also parallel with a change in rock texture. In the east the strata are prevailingly hard; in the west relatively soft, although of course to this there are certain local exceptions. From a region of soft rock more drift is supplied than from one of hard, and this is one of the reasons why the Greenland glacier has so little drift. It follows from this that in the Central States the ice wrested more drift from the bed rock and was less able to remove even a small supply than was the ice in the East. Hence beneath the glacier much till was accumulated in the western section, while in the east the opposite in general holds true.

As has been said, this general statement needs modification locally. Among the Adirondacks, and in New England, the ice currents were often retarded by some rocky hill, around which the ice must flow. Upon the southern or lee side of such a hill the conditions favored deposits beneath the ice; and consequently, while the northern side of such hills is nearly bare of drift, the southern side often has a deep till soil. In such cases the rocky hill has very often been prolonged southward as a drift hill formed by the deposit of a tail of drift upon which, very likely, a farm is situated, while all around is untillable and hence wooded land. This drift material, combed down from the hilltops and sides, and accumulated in the slack ice current on the lee side of the hills, forms a distinct element in the landscape of many of the hilly sections.

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[1] Calvin, Amer. Geol., I, 1888, 28–31; Leverett, Amer. Geol., IV, 1889, 6–21; Claypole, Bull. Geol. Soc. Amer., III, 1892, 150–151.

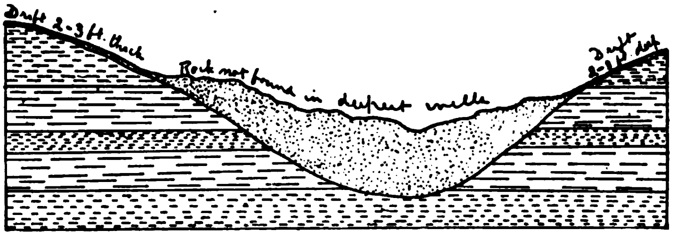

FIG. 73. Section to show deep drift-filling in narrow east-west valleys near Ithaca, New York.

Still another case may be introduced. Rather narrow east-west valleys extended across the course of the south-moving glacier, as was very commonly the case in central and western New York. Down into these the ice currents could not move as readily as along the hilltops, and hence here, too, material from the hilltops was combed off and dragged beneath the ice into the valleys. The result has been that in such valleys the till is deep, gradually becoming thinner upon the hillsides. The diagram (Fig. 73) is based upon these conditions as exhibited in scores of places near Ithaca, N. Y. In these cases the valleys have been made more shallow and their bottoms broader than before the ice came, and by these causes the topography of the New York-Pennsylvania plateau has been greatly modified.

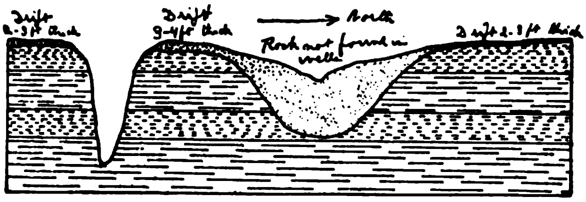

FIG. 74. Section to show buried valley of Taughannock creek, near Cayuga lake, New York.

Not only have valleys been shallowed, but in some cases they have been entirely obliterated. Near Ithaca there are numerous buried valleys, the position of some of which is not now indicated in the landscape, while that of others is shown by a gentle sag in the hillside. The diagram (Fig. 74) is based upon these conditions as illustrated just north of Taughannock gorge on the west side of Lake Cayuga, a few miles north of Ithaca. Where the general drift sheet is thick, and the original topography less irregular, as in the Central West (and apparently also in the Ontario plain region, p. 98), the preglacial drainage lines are almost entirely obliterated. By boring for oil in the Central States some of the buried valleys have been discovered, where, without the facts thus obtained, the extent of the preglacial land irregularities would not have been known.[1]

There are several other cases of irregularity in the depth of the till sheet, the exact reasons for which are not apparent. Sometimes the till is locally thicker than elsewhere without any evident relationship to the topography. Its surface rises and falls in gentle swells, or rises into hummocks or ridges. This irregularity has led Professor Chamberlin[2] to suggest certain names, such as mammillary hills, till tumuli, etc., to designate the several types. Nothing more can now be said about the cause for these than that they must be due to some such cause as variations in supply, or to ice currents, or to the influence of minor buried topographic features. They fall among the category of the altogether too numerous instances of unexplained glacial phenomena. We need specific studies of these forms and the collection of facts concerning them.

DRUMLINS.—Among the irregularities of the till none form such a striking element of the topography as those

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[1] Newberry, Geol. Survey Ohio, 1869, 24–33; Andrews, same, 60–64; Newberry, Geol. Survey Ohio, Vol. I, 1873, 85–88; 174–184; Orton, same, 425–434; 438–449; 455–462; Gilbert, 537–556, and other parts of Report.

[2] Chamberlin, Third Annual Rept. U. S. Geol. Survey, 1883, 296–309; Compte Rendu, Congrès Géol. Inter. Washington, 1891, 176–192; Journ. Geol. II, 1894, 517–538.

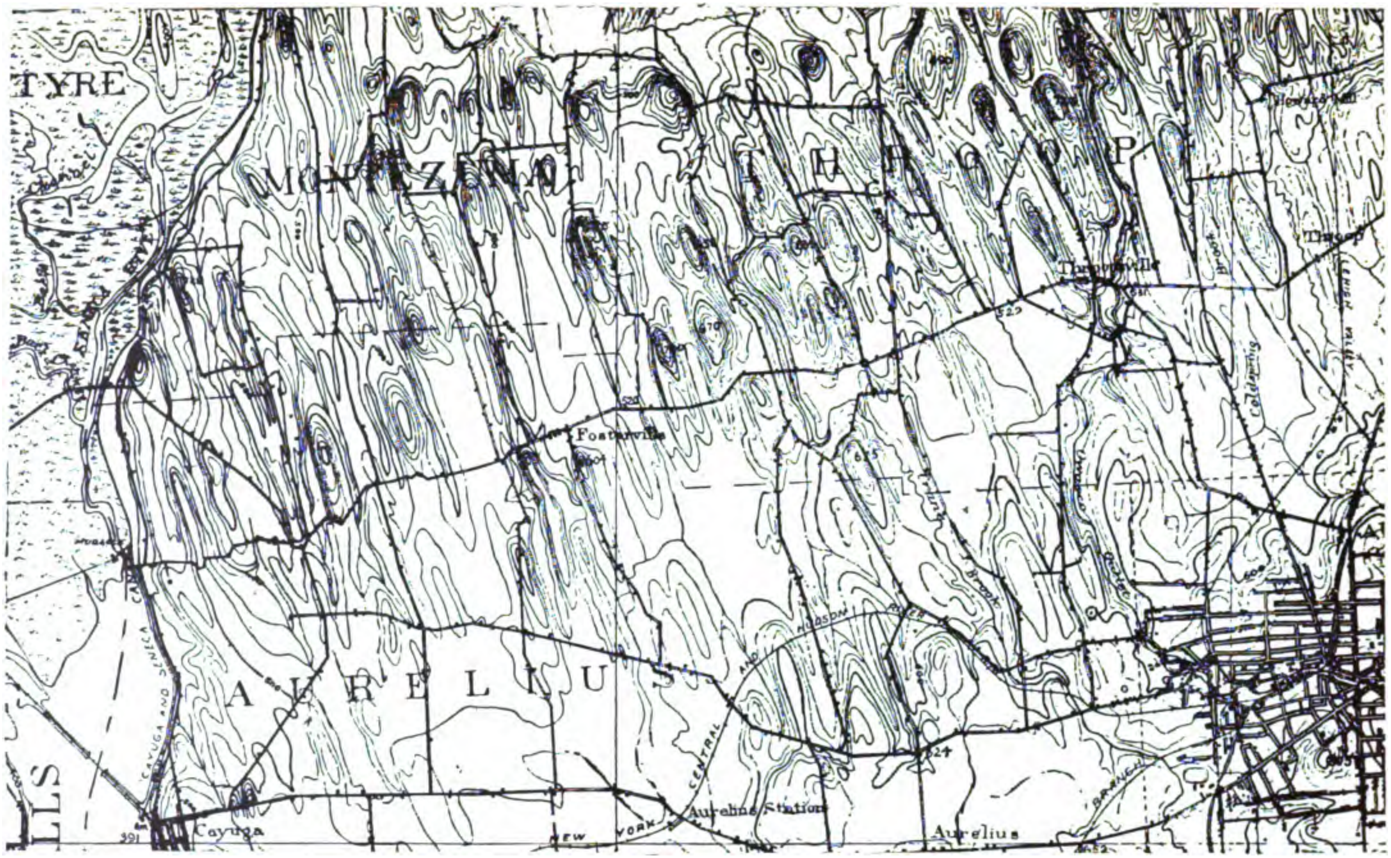

FIG. 75. A part of the drumlin region north of Cayuga lake (United States Geological Survey topographic map).

till hills which are classed as drumlins. These were first fully described in Ireland, whence their name.[1] In the United States they occur in eastern Massachusetts[2] and southern Connecticut, as well as in other parts of New England.[3] They occur also in Wisconsin.[4] Generally they are found in clusters, though many isolated drumlins are known. These peculiar hills are said to occur in the Adirondacks and in eastern New York,[5] though I find no description of these localities; but one of the most notable accumulations of drumlins in the world exists in the region between Syracuse and Rochester along the line of the New York Central Railway. As in the case of most of

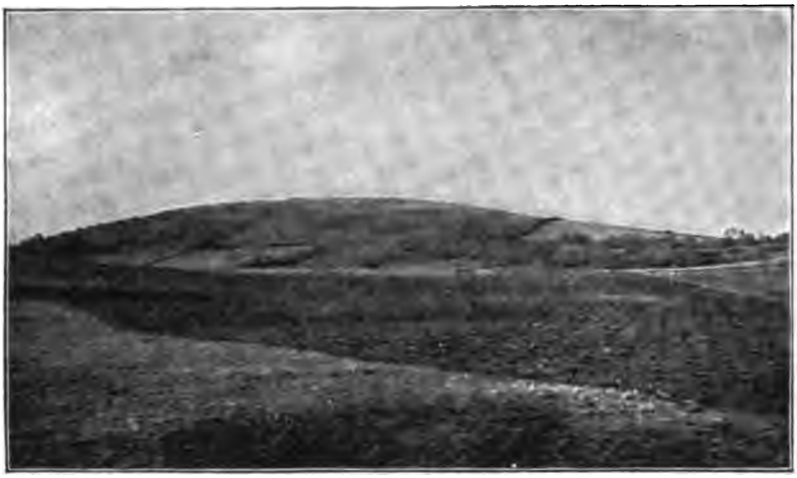

FIG. 76. A typical New England drumlin near Ipswich, Massachusetts (photograph by J. L. Gardner, 2d).

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[1] Kinahan and Close. General Glaciation of Iar-Connaught, Dublin, 1872.

[2] Shaler, Proc. Boston Soc. Nat. Hist., XIII, 1869–1871, 196–204; Upham, Proc. Boston Soc. Nat. Hist., XX, 1878–80, 220–234; Marbut and Woodworth, 17th Annual Rept. U. S. Geol. Survey, Part I, 995; Davis, Science, IV, 1884, 418–20; Amer. Journ. Sci. Ser. III, XXVIII, 1884, 407–16.

[3] Hitchcock, Proc. Boston Soc. Nat. Hist., XIX, 1876–78, 63–67; Upham, Hitchcock's Geol. of New Hamp., Vol. III, 1878, 287–309; Hitchcock, same, 309; Upham, Proc. Amer. Assoc. Adv. Sci., XXVIII, 1879, 309.

[4] Chamberlin, Journ. Geol. I, 1893, 255–267; Upham, Amer. Geol. XIV, 1894, 69–83.

[5] Upham, Bull. Geol. Soc. Amer., III, 1892, 142.

the other glacial features of New York, we have no adequate description of these interesting hills.[1]

The New England drumlin is typically a beautiful and symmetrical hill (Fig. 76), elongated in form, having a shape resembling that of an egg when half submerged in water, with the long axis parallel to the water surface. The length may be a half to three-quarters of a mile, the width a fifth to half a mile at the base, and the height perhaps one to two hundred feet. There are longer and shorter, broader and narrower, and higher and lower forms than this type. The curves are wonderfully regular, but commonly the northern end is steeper than the southern. This type is well illustrated by scores of hills in Boston harbor and near Boston, especially north of that city as far as the Ipswich coast. The long axes of the New England drumlins are parallel to the direction of last ice movement, and the material of which they are composed is mainly till, though very often they contain stratified drift.[2] The Wisconsin drumlin is often much shorter and less symmetrical,[3] the Irish type much longer.[4]

The drumlins of central New York approach the Irish type much more closely than those of New England. Their form varies from the southern margin of the belt to the northern. In the central part of the belt, they are often very much like the Boston type, though considerably less symmetrical and with steep northern faces. Near the southern margin of the drumlin belt, on the other hand, they are exceedingly long and low ridges, the length being sometimes more than two miles and the height very often less than one hundred feet at the highest point, which is close to the northern end. Some ridges, perhaps three-quarters of a mile long, are not more than forty feet high at the highest point. In fact, these low drumlins simulate the esker in form. Even many of the higher drumlins of this section change to low and long ridges in the southern part, and their exact southern terminus is often incapable of location, for it flattens out into the undulating till sheet very gradually. Sometimes this terminus is in the irregular morainic topography. In all cases the northern end is well defined and relatively steep.

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[1] Hall, Geol. of New York 4th Dist. 1843, 341; Johnson, Ann. New York Acad. Sci. II, 1882, 249–66; Abstract in Trans. New York Acad. Sci. I, 1882, 77–80; Davis, Science, IV, 1884, 419; Lincoln, Amer. Journ. Sci. XLIV, 1892, 290–301; New York State Museum Report, XLVIII, Part 2, 1894, 69–71.

[2] Upham, Proc. Boston Soc. Nat. Hist., XX, 1878–80; 220–234; XXIV, 1688–89, 127–141; XXIV, 1888–89, 228–242; Upham, Amer. Journ. Sci. Ser. III, XXXVII, 1889, 359–372; Crosby and Ballard, Amer. Journ. Sci. Ser. III, XLVIII, 1894, 486–496; Marbut and Woodworth, Seventeenth Annual Rept. U. S. Geol. Survey, Part I, 995; Upham, Amer. Geol. XX, 1897, 383–387.

[3] Chamberlin, Geol. Survey, Wisconsin, I, 1873–79, 283.

[4] Kinahan and Close, General Glaciation of Iar-Connaught, Dublin, 1872.

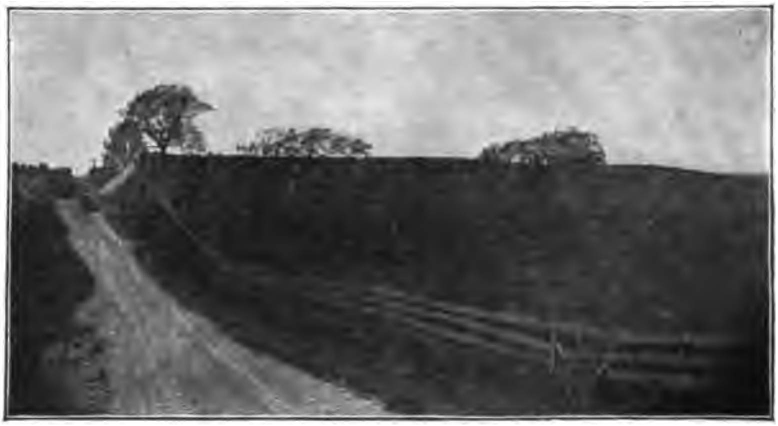

FIG. 77. Low drumlin ridge near southern margin of New York drumlin area, just east of Cayuga (photograph by W. B. Greenlee).

While some of the drumlins are long and low, with an even-topped crest line, sloping gradully southward, others have an undulating crest, giving a very ragged sky line. Whether this undulating crest is a part of the original form of the drumlin, or whether it has been caused by later denudation has not been determined, though there are some reasons for supposing that the latter is true.

Between the long and low type at the southern margin of the belt, and the shorter type of the central part there is a gradational form to which a student of Cornell University applied the descriptive name of "tadpole" drumlin. The northern end of such a drumlin resembles the central type quite closely, while the southern end is a low ridge, and the two different parts are connected by a rather noticeable slope, somewhat like the southern end of a New England drumlin. Hence the drumlinoid form, somewhat closely resembling the typical New England drumlin, quickly changes to a low and long ridge, causing a rather remarkably close resemblance to a tadpole body with the appended tail. Some of the New York drumlins are quito like the New England type in form, and all so far studied are made of unstratified till.[1] The question of the nature and origin of these drumlins is now under investigation, and it is probable that the intermediate "tadpole" forms will throw light upon the question of drumlin origin.

As in the case of all drumlins, the long axis of those in New York is parallel to the direction of ice movement, which, in this section, was approximately southward. The material composing them seems in most cases to be till of the normal kind, perhaps somewhat more pebbly than commonly; but upon this point definite statements cannot be made until further studies have been carried on. Nor can we say how many drumlins there are, though it is certain that there are many hundreds in this area; in fact, one may stand upon the crest of one and count scores which stand in plain view with their ends overlapping.

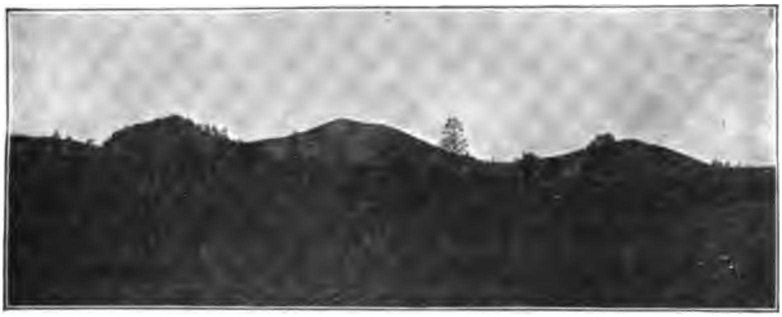

FIG. 78. The northern ends of three of the New York drumlins near Montezuma (photograph by W. B. Greenlee).

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[1] Studies carried on since this was written, but not yet published, show stratified material in many of the drumlins.

The topography of the drumlin region is quite unique in New York State, and has probably given rise to more inquiries from residents than has any other section of the State of equal population. Every year several students ask me for the interpretation of this region, a fact true of no other part of the State.

The origin of drumlins is still an open question, or at least should be, though there is a tendency on the part of some to consider it settled. Numerous theories for their origin have been suggested,[1] two of which still seem probable, while against the others numerous fatal arguments have been brought. One of these two theories is that drumlins have been caused by erosion, resulting from slightly different ice currents; the other, and more generally accepted theory, is that they have been *built* by irregular deposits from the ice, somewhat as sandbars are built in rivers. The latter has more supporters than the former; but the question can hardly be considered closed, since no

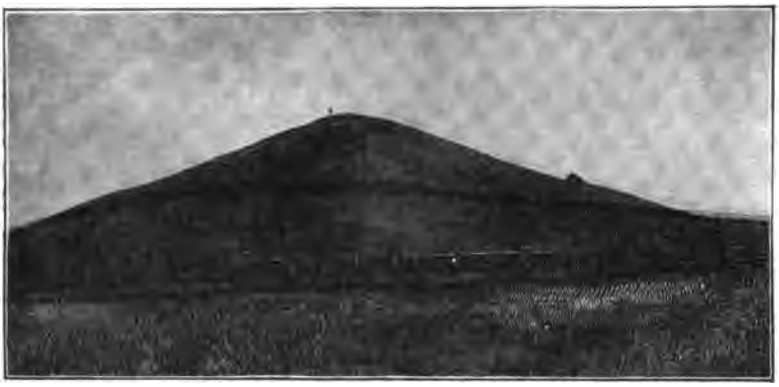

FIG. 79. Northern end of a high drumlin at Montezuma, New York (photograph by W. B. Greenlee).

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[1] See preceding references, and also Wright, Ice Age in North America, 251-267; Geikie, Great Ice Age, 3d Ed., 743-745; Russell, Glaciers of North America, 24-28; Geikie, Geol. Soc., Glasgow, Vol. III, 1867, 54; Wright, Proc. Boston Soc. Nat. Hist. XIX, 1876-78, 58; Salisbury, Ann. Rept. New Jersey Geol. Survey, 1891, 71-75; Upham, Amer. Geol., X, 1892, 339-362; Upham, Amer. Geol., XV, 1895, 194; Russell, Journ. of Geol., III, 1895, 831; Upham, Bull. Geol. Soc. Amer. VII, 1896, 17-30; Tarr, Amer. Geol., XIII, 1894, 393-407. In the latter, I have attempted to consider the two theories fairly, and have advocated the reopening of the question of origin.

facts of importance have been brought forward to disprove the former. So far the theories have been stated as conceptions of the process which probably formed the hills. Careful studies of drumlin areas are now needed to test these theories, especially since there are facts difficult to explain upon the basis of the theory of construction which has so many adherents.

GLACIAL EROSION.—That the ice eroded is proved by the fact that it was able to deposit; for it must have obtained what it deposited, together with that which went off in the water furnished by ice melting. It is further proved by the scratched stones and the glacial scratches upon the ledges; but *how much* it eroded is more difficult to prove. The old notion was that ice performed wonderful tasks of erosion and greatly modified the topography. From this extreme view there has been a reaction, and opinion has perhaps become nearly as extreme in the other direction, for there are those who deny to ice the power to do much work of erosion. That it did not erode enough to materially modify the surface in a *great* way, seems evident from an examination of the topography on the two sides of the extreme terminal moraine. Careful observation is necessary to detect the differences, which would not be the case had the ice scoured greatly in the glaciated district.

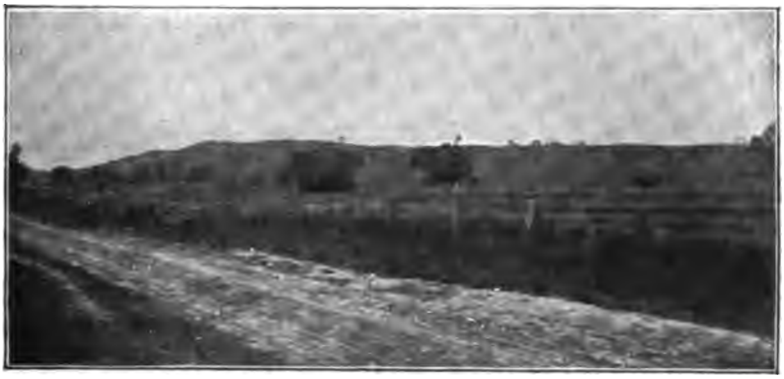

FIG. 80. Ridge-like drumlin, near Montezuma, New York, showing northern end on left (photograph by J. O. Martin).

One thing every one will admit is, that in most places the ice removed the loose débris that had accumulated in preglacial times; still there are places in New England, and probably also in New York, where even this was not done. This also argues against extreme glacial erosion; but these facts may be admitted without necessitating the view that erosion was everywhere slight.[1]

All facts, as I see them, indicate marked difference in power of erosion in different places. The hilltops were scoured more than the east-west valleys, and in all probability the hilltops of central and western New York were perceptibly lowered by ice-scouring. The proof of this would be difficult, for we know absolutely nothing of the detailed conditions before the ice came.

East-west valleys of narrow width, being transverse to the ice direction, were probably eroded very little, if any; but broad north and south valleys, like those of the Finger Lakes (p. 179), furnishing free passage to the ice, were perceptibly lowered and broadened. In such places I believe that we find the maximum ice erosion. It is in broad valleys extending in the direction followed by the ice that we find the most rapid ice movement, and hence erosion, at the margin of the existing Greenland glaciers. This is true not merely because of their breadth, but because the ice is deep in these valleys, and has a free and hence more rapid movement. Such facts would seem to be sufficient proof of this view.

There was also more rapid erosion upon the north or *stoss* side of hills than upon the south or *lee* side, against which the ice currents had little chance to scour. That this is so is amply proved by the topography of New York and other regions, where the northern slope of hills is prevailingly more regular and rounded than the southern sides. The difference may be so great as that between an inaccessible precipice on the southern and a gentle slope an the northern side of hills. This is beautifully shown

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[1] See Lincoln, Proc. Amer. Assoc. Adv. Sci. XLII, 1893, 177-8; same, Amer. Journ. Sci. Ser. III, XLIV, 1892, 290-301; same, XLVII, 1894, 105-113.

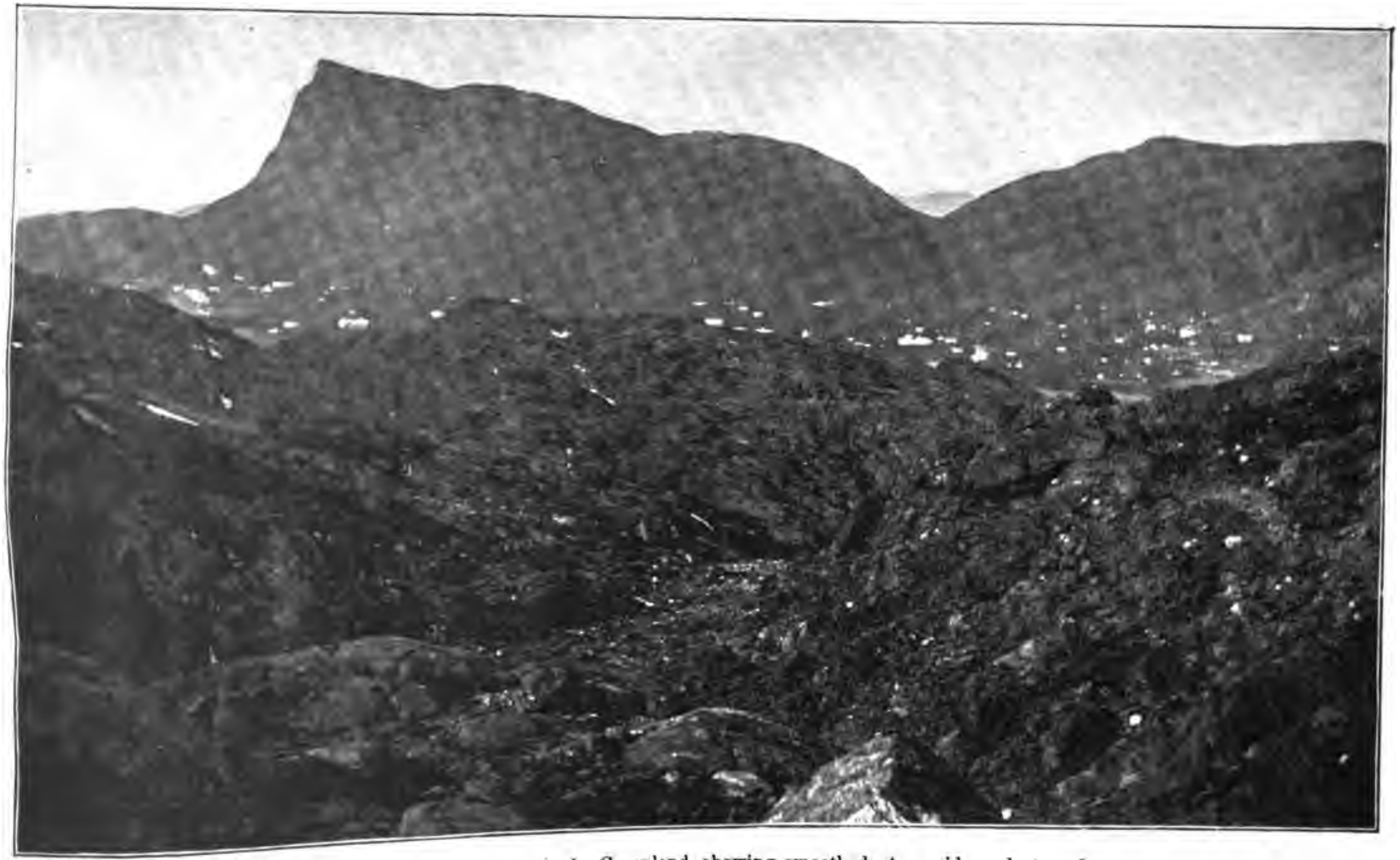

FIG. 81. Glaciated surface of upper Nugsuak peninsula, Greenland, showing smoothed stoss side and steep lee side of a hill called the Devil's Thumb on the Danish map (photograph by J. O. Martin).

in the Adirondacks, as it is also in New Hampshire and Maine, as well as in Greenland (Fig. 81), where the ice has just left the land.

Therefore, it seems that by erosion the hilltops have been slightly lowered and rounded, hill-slopes modified and rounded upon the northern or stoss end, and broad valleys parallel to the direction of ice movement both broadened and deepened. If it were necessary ample proof of this position could be brought forward. This is a statement of a belief in moderate but irregular erosion, by which the topography of the State has been perceptibly modified in details; but to *just* what extent this modification has operated, how much the hills have been lowered and rounded and the valleys deepened, may never be determined.

EFFECTS UPON DRAINAGE.—Of all the effects of the glacier, that upon drainage is most notable. Lakes have been formed and allowed to disappear. Others now existing have been caused by one or another of the effects of the glacier. Streams have been turned temporarily across divides and others given permanently to different basins, while many have been turned either partly or wholly out of their old valleys. The present drainage of New York is the complex result of preglacial topography and glacial modification; but the consideration of this important effect of the ice is left for later chapters.

CHAPTER V

THE RIVERS OF NEW YORK[1]

PREGLACIAL DRAINAGE.—In the present state of our knowledge it is quite impossible to tell much about the preglacial condition of New York drainage. As was stated on page 105, there is reason for believing that in immediate preglacial times there were few, if any, lakes within the boundaries of the State. Another fact of the preglacial drainage is that, before the ice came, there were streams where the present large valleys now stand. In other words, the larger features of hill and valley are preglacial in origin.

At present it is difficult to go much further back in time than this. The history of the development of the preglacial drainage lines has evidently been long and complex. Born near the close of the Paleozoic, during the Appalachian uplift, there have been abundant changes in the river valleys. From the history of this uplift one may well believe that the main original drainage of the State was northward and westward. As a result of the Appalachian uplift, and of the extension of this northward into Canada, combined with the mountain uplifts of earlier times in New England and the Adirondacks, there existed ranges of highlands in the east, extending from Canada to the Southern States, which must early have prohibited extensive drainage eastward from any part of New York. Westward and northward from this line of uplift there stretched extensive plains, over which streams from the rising mountains must have extended themselves as the plain increased.

From a drainage map of the eastern United States it is easily seen that this supposed original drainage, consequent upon the initial topography, is far different from that of the present. Through the Mohawk and Hudson rivers a considerable part of New York now drains eastward and southward into the Atlantic; and through the Delaware and Susquehanna a large area also drains eastward across the folded rocks of the uplifted Appalachians; but the remainder of the drainage extends either westward or northward, as most of it probably did extend at first.

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[1] For a general account of the drainage of New York, see Henry, Trans. Albany Inst., I, 1830, 87-112; Ballou, Amer. Nat., XIV, 1880, 139-140.

If this view of the early drainage of the State is correct, it becomes of marked interest to discover how it happened that streams passing westward and northward have been so changed that the drainage now finds its way across folded mountains in an easterly direction. Unfortunately, the full answer to this is not ready.

It is, however, a fact that for a long time during the Mesozoic and the early Cenozoic, the northeastern part of the United States was subjected to long-continued denudation, at the end of which the surface, even in the most mountainous sections, was certainly reduced to the condition of a low, hilly country. Some believe that it was still further reduced to the condition of a low, almost featureless plain, a peneplain (p. 100). During this long denudation there was ample time for streams to slowly change their courses and adjust themselves to conditions of rock structure and position. For instance, the west- and north-flowing streams then had a long course over a moderate grade, reaching the ocean only after passing either to that sea which was the ancestor of the present Gulf of Mexico, or to the Arctic, or to the North Atlantic near the Gulf of St. Lawrence. On the other hand, the streams that flowed eastward, on the eastern slope of the mountains, had a short, steep slope, partly due to the mountain uplift, which was still further increased in the early Mesozoic, at the time of that subsidence of the land which permitted the Triassic ocean to encroach upon eastern New Jersey and the neighboring corner of New York.

This lowered the land to the east, and must have given to the east-flowing Appalachian streams an additional slope.[1]

East-flowing streams, therefore, had in general a more favorable position for rapid extension of headwater conquest than the west- and north-flowing streams. As a result of this battle between the headwaters of the two opposing sets of rivers, the more favorably situated ones may well have encroached upon those less favorably situated, and slowly forced the divide westward, until streams on the Appalachian plateau were allowed to cross the Appalachians directly to the Atlantic.[2] Differences in climate may also have operated toward the same end, for the lofty mountains of the east must have intercepted the ocean winds, causing a much heavier precipitation on the seaward than on the landward slopes.

Succeeding the lowland condition of the northeastern section of the country, there came, during the Tertiary time, an uplift of the land which was greater in the north than in the south; and at that time the general surface of New York was raised until it stood at a level considerably higher than at present. The evidence of this uplift is stated on page 304. It seems entirely within reason to think that one of the results of the uplift may have been a change in the course of some of the rivers; for it is evident that such an uplift will increase the energy of one set of streams and decrease the energy of the opposing set, so that headwater erosion, and the conquest of stream territory, is rendered more easy. This uplift would have worked in favor of the south- and east-flowing streams, and it may in part account for some of the changes in New York State drainage. As is stated in the discussion of the Mohawk (p. 182) and other rivers, still other changes have been brought about by the glacial invasion.

It should be understood clearly that this statement of the early drainage history stands for little more than a mere suggestion. It deals with changes which are so far in the past that the facts necessary to prove the conclusions are difficult to find, and perhaps even impossible to discover. With the facts so far found, and the studies that have so far been made, little more light has been thrown upon the question of the early drainage history of New York than is contained in the general hints just put forth.

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[1] See Davis, Nat. Geog. Mag., I, 1889, 195.

[2] Davis, Nat. Geog. Mag., I, 1889, 183–253.

Concerning the changes since the immediate preglacial time, we have less difficulty in determining the facts necessary to prove the history. Our difficulty here comes chiefly from the fact that little study has been given to the problems, though there is added difficulty from the fact that in many cases the old preglacial valleys are too deeply drift-filled to permit any certainty of conclusion.

In a number of cases, however, studies have been made with sufficient care to warrant certain conclusions concerning changes in the preglacial drainage; and it is evident that modifications both of a small and large kind have been caused by the ice invasion. A few of these will be considered in some detail to serve as types. There are numerous other similar changes known, and undoubtedly a great many more will be discovered when the proper studies have been made. These type instances will be considered by examples selected first from western New York, then from central, and finally from eastern New York.

THE UPPER ALLEGHENY.—The glacier front stood for a long time in the southern part of Chautauqua and Cattaraugus counties, and while there built extensive moraines. Numerous oil borings in southwestern New York and the neighboring part of Pennsylvania, show that the drift deposits in the valleys are heavy. Some of these are in the nature of overwash plains and valley trains, but others are evidently lake deposits. North-flowing streams were ponded back by the ice dam and caused to overflow toward the south, forming lakes, the evidence of which may be seen in several of the valleys. From the filling of such valleys by glacial, stream and lake deposits, and from the cutting down of divides at the point of outflow, one may well expect to find some rivers actually reversed in their course, having originally flowed northward, but now turned southward. With the long stand of the ice front here, and with the evidence that the valleys are deeply drift-filled, such a result would normally be expected.

Another point suggesting a reversal of drainage is the nearness of the Erie-Allegheny divide to Lake Erie. From the breadth of the valleys occupied by the Great Lakes, it seems evident that in preglacial times there must have been good-sized streams in the valleys. Yet the present divide between the Erie-Allegheny drainage is so near Lake Erie that, in places, one may stand upon it in plain sight of the lake. While this is not an *impossible* condition of drainage, it is distinctly unlikely that the divide of the tributaries to a large stream should be so near the main stream. That this is an unnatural condition caused by some change in stream course is further indicated by the fact that the present divide is situated among the lower hills, amidst broad valleys, while to the southward, in the Pennsylvania plateau, the land is much higher and the valleys distinctly narrower. The real preglacial divide between the north- and south-flowing streams in this section seems, then, to have been not where it now is, but in Pennsylvania considerably south of the New York boundary.

It is to Carll[1] that we owe the positive proof that this conclusion is correct. He has shown very clearly that the Allegheny valley narrows up near Thomson's Gap, decreasing in width, from its normal breadth of approximately a mile, to about a quarter of a mile. Moreover, he has shown that the borings through the drift, which were made for oil, prove that, from this narrow gap northward, the real *rock floor* of the valley slopes northward instead of southward, as the drift-filled valley now slopes and the present stream flows. His conclusion therefore is, that the upper Allegheny, now tributary to the Ohio, was in preglacial times a north-flowing stream passing into the river that occupied the basin of Lake Erie.

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[1] Second Geol. Survey, Pennsylvania, Rept. III, 1880, 330–366.

In searching for the preglacial valley that carried its waters northward, Carll was not able to prove the *exact* place of outflow so satisfactorily as he had the fact of reversal; but, after considering the several possible valleys, he decided that the outflow was probably through the Cassadaga Valley into Lake Erie near Dunkirk.

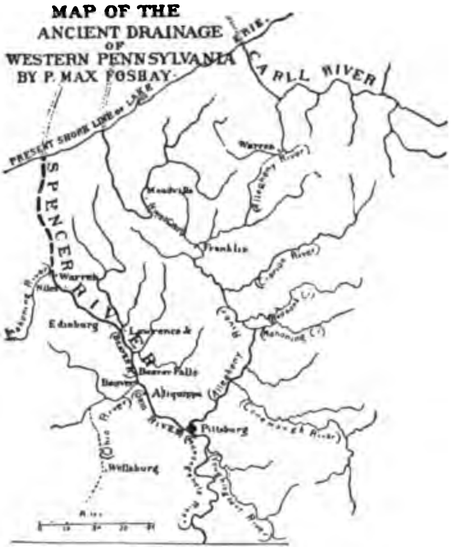

FIG. 82. Foshay's attempt at a reconstruction of the preglacial drainage of western Pennsylvania and New York.

Foshay[1] accepts this work of Carll and proposes the name Carll River for this ancient preglacial river. Chamberlin and Leverett[2] likewise accept Carll's conclusions, though not agreeing to the preglacial Cassadaga course. They show that wells in the Connewango Valley passed through 284, 314, 330 feet of drift without reaching rock, showing a deeply drift-filled valley, the continuation of which they placed further east than the Cassadaga. Their conclusion is that the preglacial course of the Upper Allegheny was into Lake Erie through the Cattaraugus Creek, which enters the lake near the town of Silver Creek (Figs. 83 and 84).

Foshay[3] shows that this is not the only important change in the direction of the tributaries of the Ohio. Following the suggestion of Spencer,[4] he studied the region of the Beaver River and has shown that the Lower Allegheny, the Monongahela and the Upper Ohio rivers united at the Beaver River and together entered Lake Erie through the Grand River. For this preglacial stream, now broken up into several parts, Foshay has proposed the name Spencer River (Fig. 82). As will be seen by the map (Fig. 84), Chamberlin and Leverett accept his conclusions in the main. It is evident that other similar reversals have occurred farther west in Ohio, so that if the Erie Basin could have its preglacial drainage, instead of being entered, as at present, by only a number of small streams, it would have several quite large tributaries, while the Ohio would be correspondingly reduced by the reversal of the tributaries which were given it as a result of the glacial invasion.

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[1] Amer. Journ. Sci., Ser. III, XL, 1890, 397–403.

[2] Amer. Journ. Sci., Ser. III, XLVII, 1894, 247–283.

[3] Amer. Journ. Sci., Ser. III, XL, 1890, 397–403.

[4] Amer. Phil. Soc., XIX, 1881, 300–337.

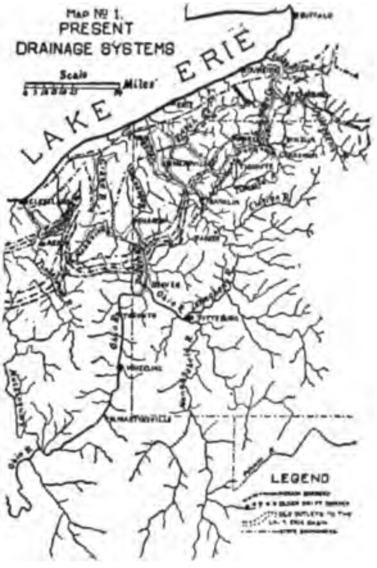

FIG. 83. Present drainage of upper Ohio with lake beaches and moraines indicated (Chamberlain and Leverett).

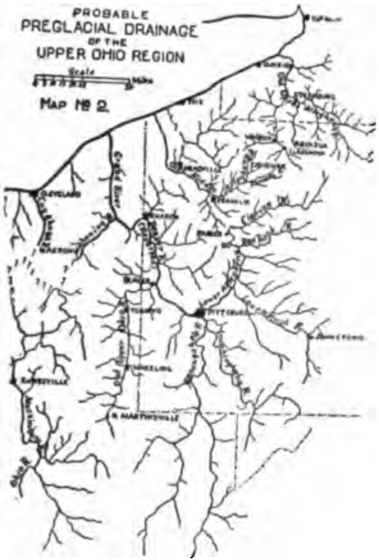

FIG. 84. Reconstruction of preglacial drainage of upper Ohio region (Chamberlin and Leverett).

THE "GULFS" OF WESTERN NEW YORK.—One of the striking topographic features of the Erie escarpment of western New York, in Chautauqua County, is the presence of numerous narrow gorges, locally called "gulfs," which breach the face of the escarpment. The small streams, flowing from the uplands of the Chautauqua County plateau, have carved steep-sided gorges in the soft Devonian shales. These are young postglacial valleys, having their origin in the fact that the drift deposits have partially, and in some cases almost completely, obliterated the preglacial valleys by filling. In some places these preglacial valleys are indicated as sags in the hillsides, occupied by streams, and sometimes by streams which have not yet cut down to the bed rock. In the latter case the postglacial valleys are rather broad gorges carved solely in the glacial accumulations. Elsewhere there are instances of streams which flow entirely outside of the preglacial valleys, and then they have carved rock gorges, frequently with waterfalls. Not uncommonly, however, the streams have their courses for the most part in their preglacial valleys; but, owing to the drift-filling of irregular form, they are often turned aside from the central axis of the valley, so that, after cutting through the drift, they find themselves at times superimposed upon the bed rock at one side of the valley. In such cases the "gulfs" are narrow, rock-walled gorges in places, and broad, drift-walled gorges in others, where their course is more nearly in accord with the preglacial valley axis. The scenery thus produced is quite like the gorge scenery of Central New York (p. 172), where the conditions, both as to local rock structure and cause, are quite similar.

DRIFT-FILLED VALLEYS ALONG THE LAKE SHORE.—Besides the partially obscured valleys on the face of escarpment, and the drift-filled valleys of the plateau, there are similar buried valleys along the shore of the lake. This is proved by the fact that the rock cliff along the shore of Lake Erie is here and there interrupted by stretches of drift without rock, notably at Dunkirk and Silver Creek. The bottoms of these valleys are below lake level, and in the case of Cattaraugus Creek, which Chamberlin and Leverett believe to be the former course of the Upper Allegheny, a well boring at Versailles, seven miles from the lake, shows the drift-filling to be at least 95 feet below the present lake level. This tends to prove that the preglacial Lake Erie valley was lower than the present lake surface; and, together with similar facts elsewhere, this has an important bearing on the question of the preglacial history of the Great Lakes.

No attempt will be made to discuss the history of Niagara River and the Great Lakes in this chapter, though at this point we may refer to the fact that, in the course of the gorge-cutting by the present Niagara, a buried channel has been revealed at the Whirlpool, and that this extends northward to the edge of the escarpment at St. David's. The exact meaning and history of this buried valley is not yet clearly understood, though there is some reason for supposing it to be the course of the Tonawanda Creek before the last invasion of the ice. It cannot properly be considered to be the preglacial course of Niagara River, for whatever the preglacial drainage of the Great Lake area may have been, there is no reason for thinking that the course of one of the great streams of the system was along the line of the present Niagara River.

Nor does this buried gorge from the Whirlpool to St. David's coincide exactly with our idea of a preglacial valley. During all the time that it had for development, such a valley should be broad, with somewhat rounded sides, having reached the form of early maturity; but this valley is a distinctly narrow, steep-sided gorge with youthful characteristics. It has been suggested that the buried gorge is really interglacial, formed possibly by the Tonawanda Creek during the interval between the first and second advance of the ice sheet.

It does not require a long nor very detailed study of the drainage features of northern and western New York to see that this *gorge* condition of parts of valleys, now filled or partially obscured by drift, and hence antedating the last advance of the ice, is a feature that will have to be taken into full consideration before the studies of the drainage history are complete. Some cause has introduced gorges of earlier date than the drift-filling, and has introduced them in connection with distinctly preglacial valleys. What this cause is we are not yet prepared to state, though interglacial stream-cutting seems the best hypothesis in the present stage of the investigation. This question is briefly considered below (p. 177).

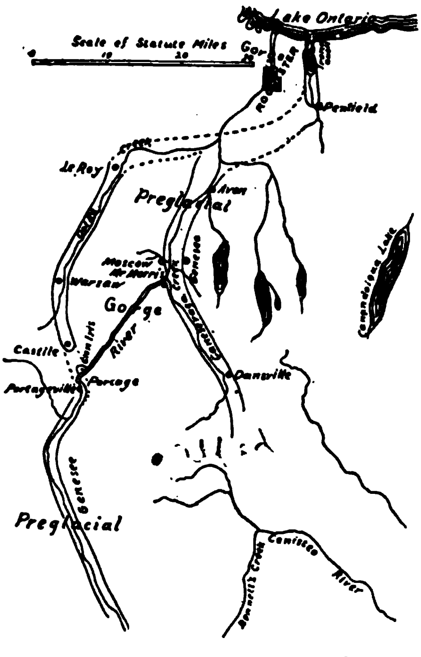

FIG. 85. Map showing condition in Genesee Valley with probable preglacial course indicated (Grabau).

THE GENESEE RIVER.—Owing to the early settlement of Rochester, and the presence of the falls there, the lower part of this valley long ago attracted attention, and it was early recognized that the lower gorge had been carved out by the action of running water.[1] The first description at all adequate was by Hall,[2] who states some of the more important facts in the history of the valley.

The Genesee is the only river which crosses the entire State, rising in Pennsylvania, just south of the boundary, and flowing northward into Lake Ontario, just to the north of Rochester. The valley presents some interesting peculiarities, for there are four quite distinct parts to it.[3] From the headwaters to Portageville (Fig. 85) the river flows in a broad, mature valley, evidently preglacial in age, and partly filled by a deposit of drift. At Portageville the valley abruptly changes its character, for the stream here enters a rocky gorge, through which it passes for over 25 miles, as far as Mt. Morris. "This gorge varies in width from six hundred to about eight hundred feet, and its sides are mostly perpendicular, rising in places to a height of four hundred feet or more. In this gorge are situated the three celebrated Portage Falls"—the first having a height of 66 feet, the second of 110 feet and the third of 96 feet.[1]

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[1] See, for instance, Bigsby, Amer. Journ. Sci., II, 1820, 250–54; Wadsworth, same, XVIII, 1830, 209–210; Silliman, same, XVIII, 1830, 210–211; Hall, Geology of New York, Fourth Dist., 1843, 377–382.

[2] Geol. of New York, Fourth Dist., 1843, 342–347; 368–374.

[3] Grabau, Proc. Boston Soc. Nat. Hist., XXVI, 1894, 359–369.

Below the gorge, from Mt. Morris to Rochester, the valley is again broad and preglacial in characteristics, though wider than the upper valley. The bottom of this part of the Genesee Valley is drift-filled to the depth of at least one hundred or two hundred feet. A part of this filling is due to the presence of a lake that was dammed back by the glacier when it reached across the valley.[2] At Rochester the river enters a second gorge, and for seven miles flows through it until Lake Ontario is reached. In this postglacial gorge there are three falls, the upper one, over the hard Niagara, being 98 feet high, the second, over the Clinton, 20 feet high, and the third, over the hard upper Medina sandstone, 105 feet high.[3]

So the valley is a complex of two preglacial and two postglacial courses. To the west of the middle Genesee there is a broad preglacial valley occupied by the Oatka Creek. It is fully a mile wide, which is about the width of the Genesee above Portageville, and it is quite deeply drift-filled, as is the Genesee itself, the drift being a hundred and fifty to two hundred feet deep. This valley seems altogether too large for so small a stream to make. While the direct connection between this and the upper Genesee has not been discovered, Grabau is of the opinion that the Oatka Creek really represents the continuation of the preglacial upper Genesee. Chamberlin[4] points out that

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[1] Grabau, Proc. Boston Soc. Nat. Hist., XXVI, 1894, 359–360.

[2] Hall, Geol. of New York, Fourth Dist., 344; Davis, Proc. Boston Soc. Nat. Hist., 1882, XXI, 361; Grabau, Proc. Boston Soc. Nat. Hist., XXVI, 360; Fairchild, Bull. Geol. Soc. Amer., VII, 1896, 434–452.

[3] Grabau, Proc. Boston Soc., Nat. Hist., XXVI, 1894, 361.

[4] Third Annual Report, U. S. Geological Survey, 1883, 351.

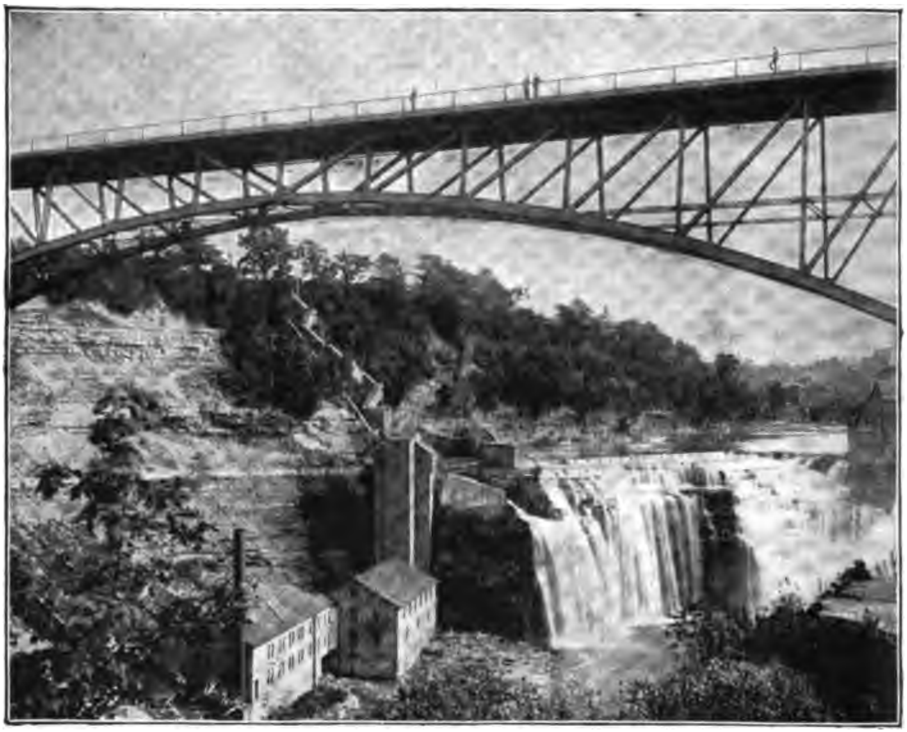

FIG. 86. Lower Genesee Falls.

there is much moraine near Portageville, and suggests that the real channel of preglacial Genesee lies to the east of the gorge course, instead of to the west, as Grabau has suggested.

To the east of the middle Genesee there is another broad preglacial valley, occupied by the Caneseraga Creek, which joins the Genesee just below the Portageville-Mt. Morris gorge. This valley appears to be a preglacial tributary of the middle portion of the Genesee. According to the views of Grabau, which will be found stated more fully in his paper, the upper Genesee turned westward into the Oatka Creek and joined the valley now occupied by the Genesee at some point below Avon.[1] This river received the tributaries occupying the valley which is now the site of Caneseraga Creek and the middle preglacial portion of the Genesee. The exact place of union of these two streams has not been proved.

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[1] R. H. Whitbeck has carefully studied the upper gorge of the Genesee, and disagrees with Grabau. He holds that the river turned eastward; and that the problem is complicated by an interglacial gorge, now partly buried. The result of this work is to appear in the Bull. Amer. Geog. Soc., Feb. 1902.

The postglacial gorge from Rochester to Lake Ontario represents a further turning aside of the stream from its preglacial course by which it was forced to cut into the rock. To the east of Rochester there is a broad valley extending from the lake to Penfield. At the north it is fully a mile wide, where it forms a bay called Irondequoit Bay, which is partially shut off from the lake by a sand-bar. This valley is at least 250 feet deep. The suggestion naturally arises that the Irondequoit Bay represents the preglacial course of the lower Genesee, and this suggestion was actually made by Hall as long ago as 1843.[1] It has since been restated by Dryer;[2] and Grabau[3] thinks that it was at least the former outlet of the preglacial Caneseraga, and, if the Genesee united with this, of the Genesee also. There are extensive drift deposits near Rochester consisting of moraines, kames and drumlins, so that the ancient valley may well be entirely obscured by these deposits.

There are probably other changes in the Genesee valley, especially about the headwaters, similar to those found further east in theFinger Lake region (p. 170); but no work has been done upon this region. With reference to the changes recorded above, it may be stated that, while some points are as yet uncertain, it seems that the two gorges call for some such changes as those outlined; and, while the conclusions of Grabau may be somewhat modified in detail by future studies, the main fact — that the present Genesee follows a course which is different from the preglacial course in the two gorge portions—may be considered proved.

THE CHEMUNG VALLEY.—There are no publications relating to the conditions in the upper Susquehanna and its tributaries. Having worked to some extent in this valley, I have seen that there are problems of importance connected with the changes in river course. It is not improbable that some of this drainage found its way northward through the valley of Seneca Lake; but the evidence of this is not yet complete enough for a discussion of the subject.

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[1] Hall, Geol. of New York, Fourth Dist., 1843, 344, 422.

[2] Amer. Geol., V, 1890, 202-207.

[3] Proc. Boston Soc. Nat. Hist, XXVI, 1894, 364.

Nevertheless it should be pointed out that at Havana, four miles south of the lake, a well in the middle of the valley passed through 435 feet of drift without reaching rock,[1] and that six miles south of this a well 186 feet deep did not reach rock. From this it is seen that the valley is deeply drift-filled, being occupied by a heavy deposit of moraine. It is also a broad valley and may possibly represent the course of a north-flowing preglacial stream, which received tributaries from south of the present divide. In any event, it is certain that the present divide is determined by drift deposits, not by the bed-rock outline, as it was in preglacial times, and therefore that its present position is not the exact preglacial one.

One notable change of glacial origin is illustrated on the Elmira sheet of the U. S. Geological Survey (Fig. 87). It will be seen that the Chemung, flowing from the west in a broad valley with flat bottom, abruptly leaves it, passing through a very narrow valley behind a large and high hill, and emerges again into the old and broad valley at Elmira. In doing this, it makes a shorter cut from near Big Flats to Elmira; but while this is true, it is noticeable that the stream leaves what was evidently its preglacial course past Horseheads.[2] No rock is found in the stream-bed, either in the broad main valley or in the narrow valley now occupied by the river. It is evident from this that the Chemung has not made a postglacial cut in passing from Big Flats to Elmira.

The conditions of the valley are these: A massive moraine occupies the upper or southern part of Seneca Valley as far as Pine Valley; and while the ice was standing there

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[1] Lincoln Amer. Jour. Sci., III, XLVII, 1894, 109.

[2] This valley has been studied by Mr. N. H. Farnham, of Cornell, who has written an undergraduate thesis upon the subject and deposited it in the Cornell Library. To Mr. Farnham's thesis I am indebted for some of the facts stated here. Space prohibits a full statement of all the evidence, which will be published in due time elsewhere.

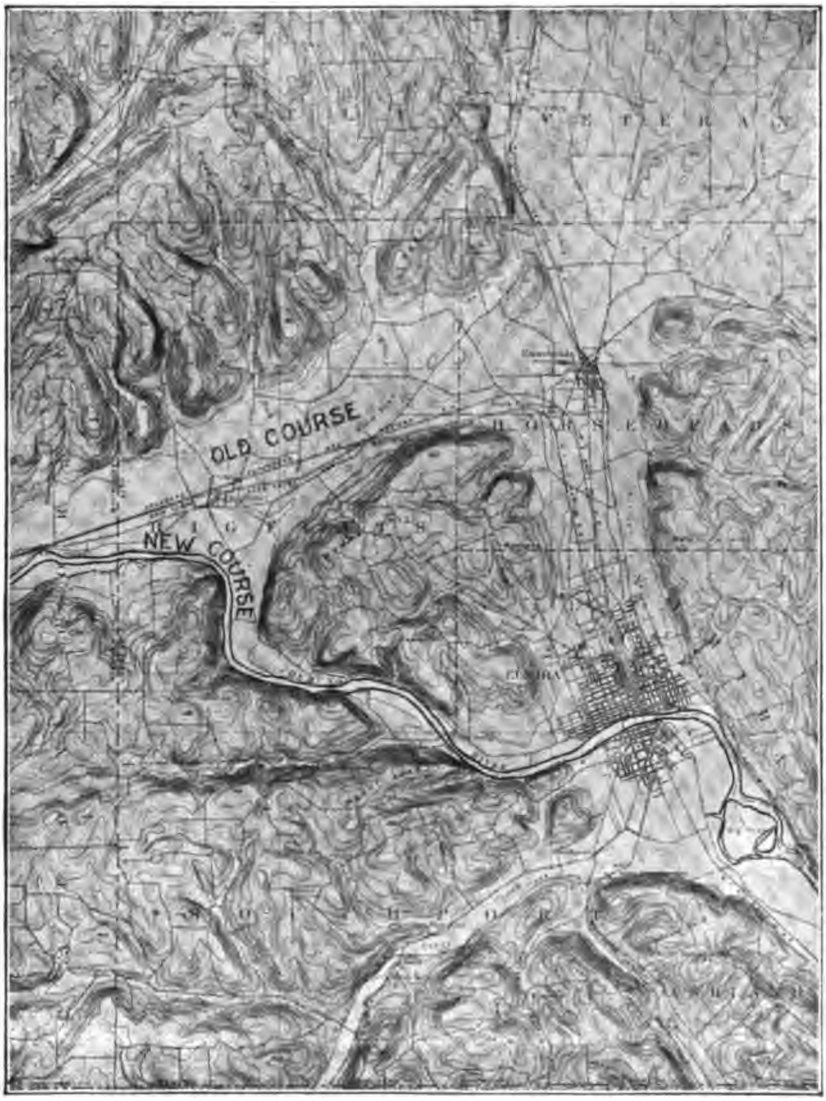

Fig. 87. Elmira Sheet, showing abandoned preglacial valley (United States Geological Survey, Topographic Map).

building this moraine, floods of sediment-laden water were poured into the Chemung, to which were added other contributions from the tributary streams to the west of this. These glacially furnished gravels form a notable part of the filling of the abandoned Chemung Valley.[1] The flat-bottomed valley is the product of the overburdened condition of glacially supplied water, and it forms a very typical overwash plain.

Prior to this flooding there had been two small tributaries to the Chemung, heading on the southern side of the hill, in the narrow valley now occupied by the Chemung. From the map one readily sees where the preglacial divide was situated; for the valley behind the hill broadens both ways from this narrow divide section. The glacial floods choked these small tributaries with sediment until their bottoms were raised above the level of the divide between them, so that, when the sediment supply ceased, it was possible for the Chemung to pass behind this hill, being prevented from flowing through its old valley because of the slightly greater elevation there, caused, no doubt, by the fact that the sediment supply was greater from the Seneca Valley than from the others, thus causing a more rapid filling near Horseheads than in the more remote valley near Big Flats and along the present narrow course of the Chemung. In other words, this is an overwash plain with the form of an alluvial fan.

REVERSAL OF DRAINAGE NEAR LAKE CAYUTA (Fig. 41).— Doubtless there are hundreds of cases of changes in drainage in New York similar to these which have been discussed, though practically nothing has been published upon them. As further illustration of accidents to river courses, I propose to state some of the changes near Cayuta Lake which have been carefully studied. These will serve as illustrations of types rather than because of their intrinsic importance.

Extending from Cayuta Lake southwest to the Seneca Valley is a broad valley choked with extensive morainic deposits. It is a direct continuation of the Cayuta Lake valley (see U. S. topographic map, Watkins sheet), and yet the outflow of the lake is not through this broad valley, but to the southeast, where it passes through a narrow gorge cut in the hills.[1] If the water went as one would expect from the general topography, and as it evidently did in preglacial times, it would have entered Seneca Lake and thence have passed northward, provided the stream occupying the Seneca valley flowed as the water now runs. Instead of this it now passes southward into the Atlantic through the Susquehanna.

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[1] There are other deposits than these in the valley, notably till, partly and in places completely buried beneath the gravels.

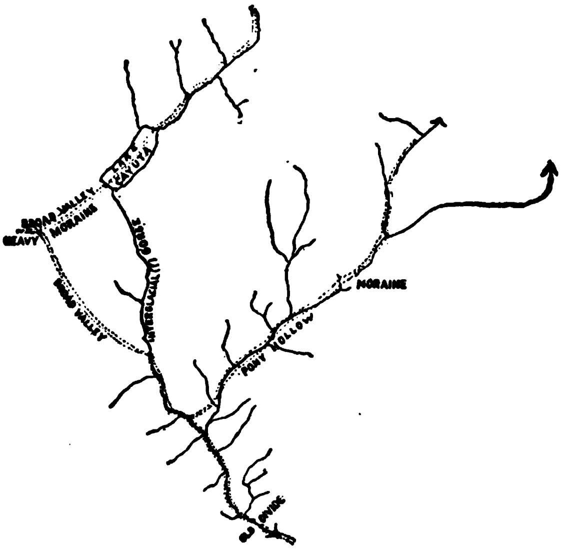

FIG. 88. To show present and preglacial stream courses near Cayuta Lake.

There are other changes near here. By examining the Ithaca sheet of the U. S. Geological Survey (Fig. 41) it will be noticed that a series of hills stretch across the valley of Pony Hollow at the place which is now the divide. These hills are a part of the terminal moraine (marked moraine in Fig. 88) and their height has prevented the postglacial streams in that vicinity from taking their preglacial courses. The real preglacial divide of the Pony Hollow stream is near Newfield on one branch, and near Trumbull's Corners on the other. By the filling of the Pony Hollow valley the stream has lost fully half of its volume. This amount of water has been turned from the

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[1] This appears to be an interglacial cut. See p. 177.

Seneca into the Cayuga Valley. In addition to the moraine filling in the Pony Hollow Valley, there are also extensive deposits of overwash material, which have transformed the valley bottom to a broad overwash plain.

Cayuta Lake and the Pony Hollow stream, in preglacial times larger than now, at present unite to form Cayuta Creek, which flows southward to the Susquehanna. The map (Fig. 41) shows the valley narrowing in the direction of flow of these streams until Cayuta Creek reaches a narrow gorge, south of which the valley again broadens. The topographic evidence here, therefore, points to another case of reversal, the site of the gorge being a divide similar to that of Thomson's Gap in the Upper Allegheny. Thus the topographic evidence points toward the westward flow of this part of Cayuta Creek in preglacial times, when it received tributaries from the Pony Hollow stream and Cayuta Lake Valley. These, uniting, flowed westward into the Seneca stream through a broad valley now deeply drift-filled and occupied by only one or two very tiny streams. Evidence of these changes is only less complete than that of the Allegheny by the absence of borings to show that the conclusions from topography are verified by rock bottom slope.

GORGES OF THE FINGER LAKES REGION.[1]—In central New York there are many postglacial gorges cut in the Devonian shales, and in them are a great number of picturesque waterfalls. In each case the gorge represents a new stream course caused by diversion resulting from drift deposits. While each case presents peculiarities of its own, I shall select only a few near Ithaca to serve as types of the others, among the most noted of which are Watkins and Havana Glens at the head of Seneca Lake. The region about Ithaca, as also that about Seneca Lake, and the head of the other Finger Lakes, is one of heavy drift deposits, connected with the moraine of the "second glacial epoch" (p. 127). The ice passed rather freely along the axis of these north-south valleys and partially scoured them out; but the tributaries from east and west, instead of being deepened, were shallowed by drift deposit (p. 143), especially near the lake valley. Consequently, when the streams began to flow after the ice had withdrawn, they were often obliged to seek new courses because their old valleys were so deeply drift-filled. This was the cause for the gorges and the waterfalls that have developed during the process of gorge-cutting.

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[1] Hall, Geol. of New York, Fourth Dist., 1843, 377–382; Macfarlane, Science, IV, 1884, 99–101; Lincoln, New York State Museum Report, 48, Part 2, 1894, 67–68.

In the case of Six Mile Creek, which enters the Cayuga Valley from the east at Ithaca, the postglacial stream occupies the preglacial valley throughout its distance; but, because of the drift-filling, it is not now flowing at all places along the *lowest* part of the old valley. So, as in the case of some of the "gulfs" of Chautauqua County, this creek has in places cut through the drift to find itself superimposed upon the rock wall of a part of the old valley. Where this is the case, we have a rock-walled gorge, often with falls and rapids, while in other parts the valley is broad and drift-walled, forming what are locally known as "amphitheaters." In passing up this valley one comes first into a gorge, then into a broad amphitheater, and again into another gorge, etc. Each gorge represents a place where the postglacial stream has cut into the rock

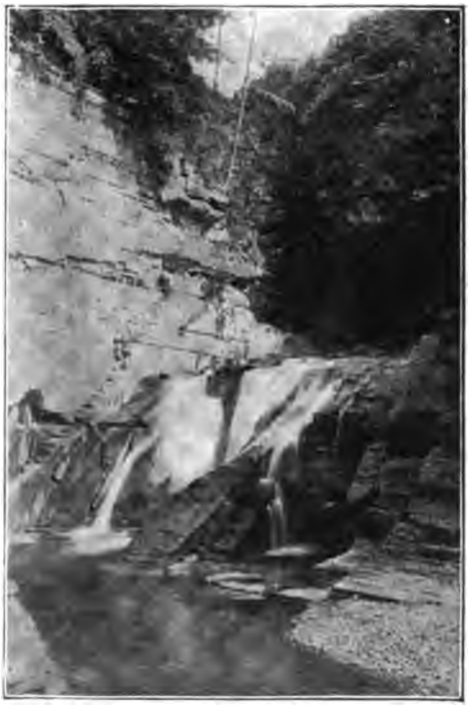

Fig. 89. Green Tree falls in a postglacial gorge section of Six Mile Creek (J. O. Martin, photographer).

banks of the older valley; and each amphitheater is a place where the present stream flows near the center of the older valley, so that it has not yet reached the old rock floor.

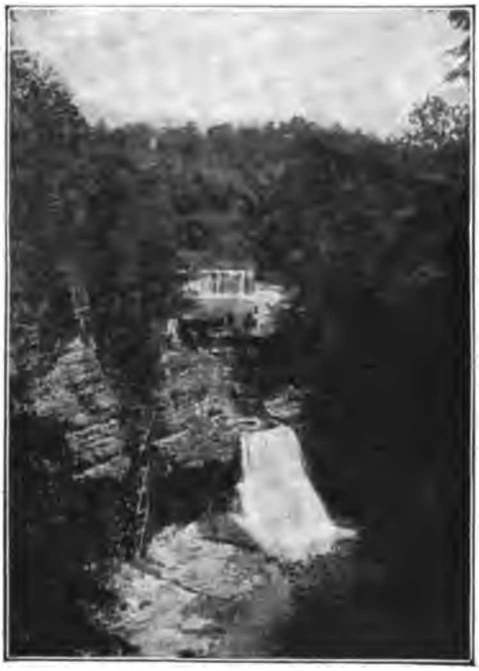

FIG. 90. Triphammer Falls in Fall Creek on northern boundary of Cornell Campus

Buttermilk Creek, south of this, occupies its preglacial course down to the distance of about a mile from the Cayuga Valley, where it leaves it and cuts a rock gorge, while the older valley is traceable just north of the gorge, where it is seen in the form of a broad valley filled with drift. The conditions at Fall Creek are similar to Buttermilk, the old valley being here also to the north of the postglacial gorge; and the same is true of Taughannock gorge, in which is found the highest fall in the State, where the water falls vertically for a distance of 215 feet. Here the old valley is also north of the postglacial gorge. Coy Glen, southwest of Ithaca, presents similar conditions; but in this case the preglacial valley is *south* of the postglacial.

In all these cases the old valley is abandoned by the stream at a distance of one or two miles from the lake valley. There are reasons for this, one being that the preglacial valleys are more completely obliterated by drift-filling near the lake than on the high land further back from it. Another is that as the ice went down the Cayuga valley glacial erosion scoured not only the valley bottom, but its sides,

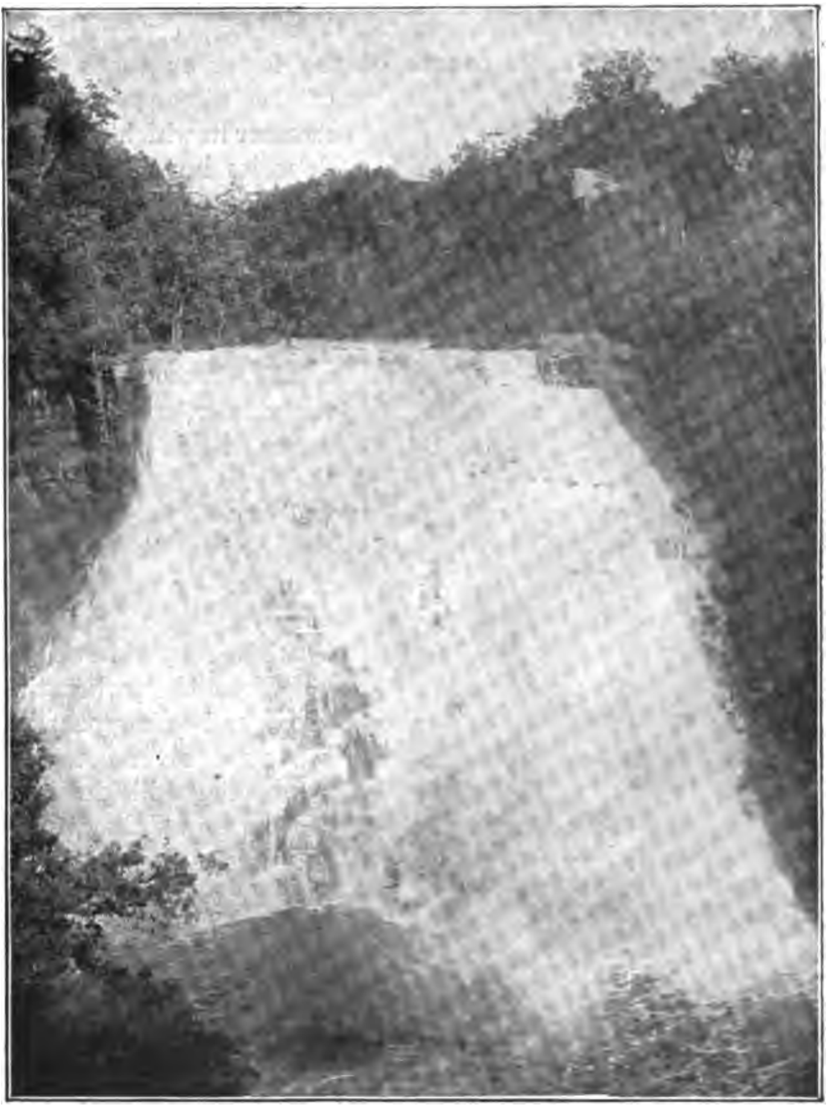

Fig. 91. Ithaca Falls at the outlet of Fall Creek Gorge near the Cornell Campus.

thus lowering the tributary valley walls so that less filling was necessary to obliterate them. A third reason for the abandonment of the older valleys is the lake deposits; and this is the most important reason, especially in determining the *exact* course of the lower or gorge part of the streams. The manner in which the lake deposits have brought this diversion about calls for a fuller statement.

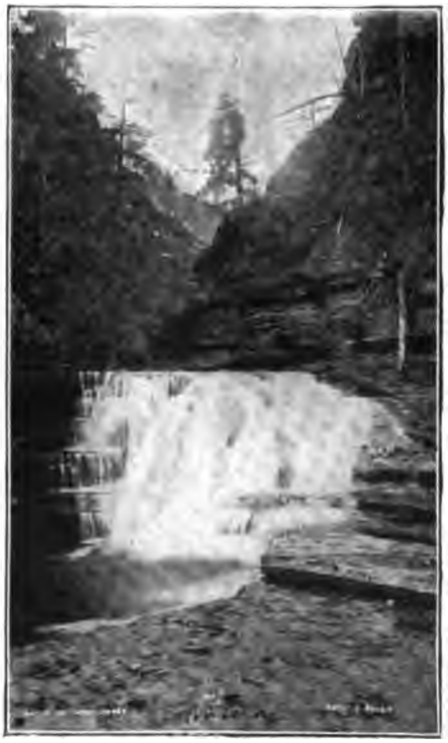

FIG. 92. Step Fall over several hard layers, Enfield Gorge (McGillivray, photographer).

When the ice was leaving it, the Cayuga valley was occupied by a lake, dammed back by the glacier,[1] and the evidence of this is found in the form of remarkably well-developed deltas opposite the stream mouths. These deltas completed the filling of the older valleys in places, so that, when the lake had disappeared, the new river-courses, down the hillside into the Cayuga Valley, were determined by the position that the streams happened at that time to have upon the deltas which were just being abandoned. Each stream naturally began cutting a gorge at the very place where it was flowing at the time the lake disappeared, and this accounts for the very remarkable condition at Taughannock Falls, where the new course has been begun on the hillside instead of in the lower ground of the partially filled older valley (Fig. 94). The first place where the stream leaves its older valley is, therefore, at the site of the uppermost delta; and, as the lake dropped by successive stages, indicated by successively lower deltas, the stream course was locally redetermined by the lower deltas during the process of lake withdrawal.

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[1] Fairchild, Bull. Geol. Soc. Amer., VI, 1895, 353–374; Watson, New York State Museum Report 51, Part 1, 1891, r55–r117.

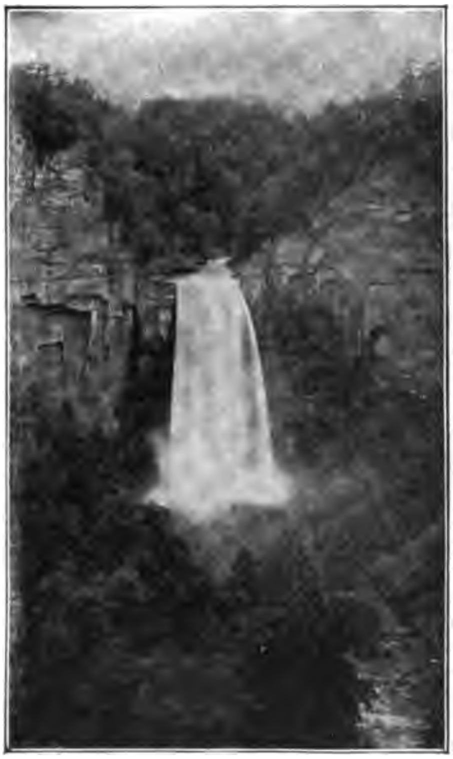

FIG. 93. Taughannock Falls and Gorge.

The presence of the new gorges on the *south* side of the old valleys, which is the prevailing condition, is due to the effect of the north winds on the extinct lake, which forced the deltas, and therefore the river courses, to the southward. The reason why this is not so in the case of Coy Glen is that its situation is protected from the north winds, but exposed to those from the south. What is said of these specific cases will apply in general to many of the other gorges of the Finger Lakes.

In the gorges are many remarkable waterfalls. Of these there are two main types—one represented by Taughannock (Fig. 93), where the fall is straight down, and the other by the Ithaca Falls (Fig. 91), where the falls consist of a succession of steps. The former is the Niagara type, and occurs where there is a hard layer to hold the fall at that level, or where, as in Taughannock, the joint planes favor a steep fall. The latter is found either where there is no unusually hard layer or no perfect development of joint planes, or else where there are several hard strata near together with intermediate beds of soft rock.

These falls are in process of change, those of the Niagara type moving upstream, and maintaining their height at the level of the hard stratum, while the second type is being transformed to rapids (Fig. 92). In both cases they had their birth as the result of the accident which turned streams to one side of their old courses and caused them to tumble down a steep hillside, in which they have undertaken the task of carving a valley, which has now reached this stage of development, varying slightly under different conditions, but in all cases being a gorge with rapids and falls.

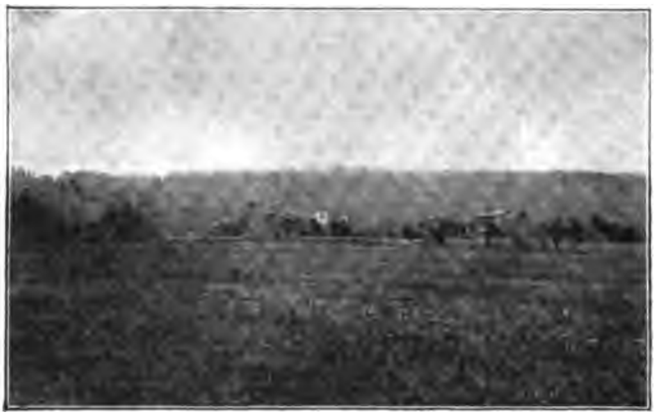

FIG. 94. Looking into drift-filled valley of preglacial (interglacial ?) Taughannock.

INTERGLACIAL (?) GORGES.—In central New York there are numerous gorges which are broader than the postglacial valleys and partially obscured by glacial till, showing that they were formed either during preglacial or interglacial times. This class of valley is especially well illustrated in Six Mile Creek, where its relation to the broad, mature preglacial valley is well shown (Fig. 95). In one case near Taughannock Valley, lakebeds containing fresh water fossils have been found beneath the till.

Space forbids a discussion of this subject, since the exact origin of these gorges is not yet determined. When studies have reached over a wide enough area, the facts concerning their distribution and origin will be brought forward; but at this time only the fact of their existence is mentioned, in the hope that it may reach the eyes of some who are working on the physiography of other parts of the State where similar gorges exist. The question is a large one, and not to be settled by the study of a single valley. One naturally thinks of these gorges as being interglacial in origin, and this explanation seems at present the most probable; but all that can now be said with certainty is that they antedate the last advance of the ice. The question of these gorges has a very important bearing upon the whole subject of the drainage history of central and western New York. Were the gorges due to the interglacial conditions or to an uplift of preglacial times?

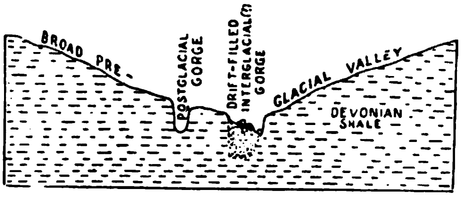

FIG. 95. Cross-section of Six Mile Creek showing preglacial, interglacial (?) and postglacial valleys.

FORMER CONDITION OF THE FINGER LAKE VALLEYS.—Much has been written upon the origin of the Finger Lakes of New York.[1] There is uniformity of agreement that they represent preglacial valleys, and the later workers are agreed that they represent preglacial valleys in some of which, at least, the streams flowed northward. There is a further agreement that they have been transformed to lakes by glacial action, though there is no general agreement as to the exact cause for this change. It seems certain that at least Cayuga, Seneca and the larger valleys to the west of these, which now enter Lake Ontario through the Oswego, had a more direct northward course in preglacial times. As early as 1843 Hall suggested[1] that, prior to the formation of the Cayuga marshes, the outflow of Lakes Cayuga and Seneca was into the Ontario Valley through Port Bay. North of the Finger Lakes there is a broad valley transformed to a bay, which seems very likely to be the preglacial continuation of one or several of these valleys, though now choked with an extensive accumulation of drift, some of it in the form of drumlins, through which the Seneca River now finds its way in a winding course. This region is so drift-filled in places that there is no surface sign of a preglacial valley.

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[1] Some of these refer to the origin of the Great Lakes. For a more complete bibliography see Ch. VII and VIII. Vanuxem, Geol. of New York, 3d Dist. 1842, 237; Hall, Geol. of New York, 4th Dist., 1843, 321; 405–6; Newberry. Proc. Boston Soc. Nat. Hist., IX, 1862, 42–46; same, Annals New York Lyceum Nat. Hist., IX, 1870, 213–234; same, II, 1874, 136–138; same, Geol. Survey of Ohio, II, 1874, 72–80; same, Proc. Amer. Phil. Soc., XX, 1882–83; 91–95; Simonds, American Naturalist, XI, 1877, 49–51; same, Amer. Geol., 1894, XIV, 58–62; Foote, Notes Upon Geological History of Cayuga and Seneca Lakes, Ithaca, N. Y., 1877, 14 pp. (Thesis presented for the degree of doctor of philosophy at Cornell University, June, 1877); Shaler and Davis, Illustrations of the Earth's Surface, Boston, 1881, 52; Davis, Proc. Boston Soc. Nat. Hist., XXI, 1882, 359–361; same, XXII, 1882–83, 19–58; Spencer, Proc. Amer. Phil. Soc., XIX, 1881, 300–337; same, Amer. Geol., XIV, 1894, 134; Johnson, Annals New York Acad. Sci., II, 1882, 249–266; Chamberlin, 3d Annual Rept. U. S. Geol. Survey, 1883, 353–360; Wright, The Ice Age in North America, 3d Ed., 1891, 323; same, Man and the Glacial Period, 1892, 94; Lincoln, Amer. Jour. Sci., XLIV, 1892, 290–301; same, XLVII, 1894, 105–113; same, New York State Museum, Report 48, Part 2, 1894, 60–125; Brigham, Bull. Amer. Geog. Soc., XXV, No. 2, 1893, 1–21; Tarr, Bull. Geol. Soc. Amer., V, 1894, 339–356; same, Amer. Geol. XIV, 1894, 194.

With reference to the cause for the transformation of the north-south valleys to lakes there are two opposing explanations. One is that they are clogged with drift, the other is that they are gouged out by ice erosion. In all probability the true explanation is a combination of these two. The erosion theory, as a partial explanation of the depth of these valleys, was proposed in 1892 by Lincoln,[2] and for Lake Cayuga in 1894 by myself.[3] The conclusions stated in my earlier paper have stood the test of much more extended studies, so that, after seven years, I am even more fully convinced that the two larger lakes owe their depth below the lake surface in large measure to ice erosion, and that they are in the nature of rock basins. Additional facts have been brought to light in support of this theory and none opposed to it. The only modification of the original proposition is that coming from the study of the supposed interglacial gorges; and since these are not now fully understood, it is impossible at present to state just what this modification will be.

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[1] Hall, Geol. New York, Fourth Dist., 1843, 415.

[2] Lincoln, Amer. Jour. Sci., XLIV, 1892, 290–301.

[3] Tarr, Bull. Geol. Soc. Amer., V, 1894, 339–356.

Therefore, the explanation which I shall put forward for the Finger Lake Valleys is that there existed here several north-flowing streams, occupying preglacial valleys, some of which united and entered the Ontario stream somewhere north of Lakes Cayuga and Seneca. Without doubt some of the smaller of these Finger Lakes have been formed almost, if not entirely, by glacial deposits; but the two largest have their origin only in part as the result of glacial deposit. They offered broad channel-ways, along which the ice stream moved much more easily than upon the neighboring irregular hilltops. Not only was the movement more rapid, but the depth of the ice was greater. The position of the rocks, dipping southward, and the nature of the friable shales, conspired toward rapid erosion; and so these north and south preglacial valleys were markedly deepened.

Evidence of this comes from the side streams. The rock

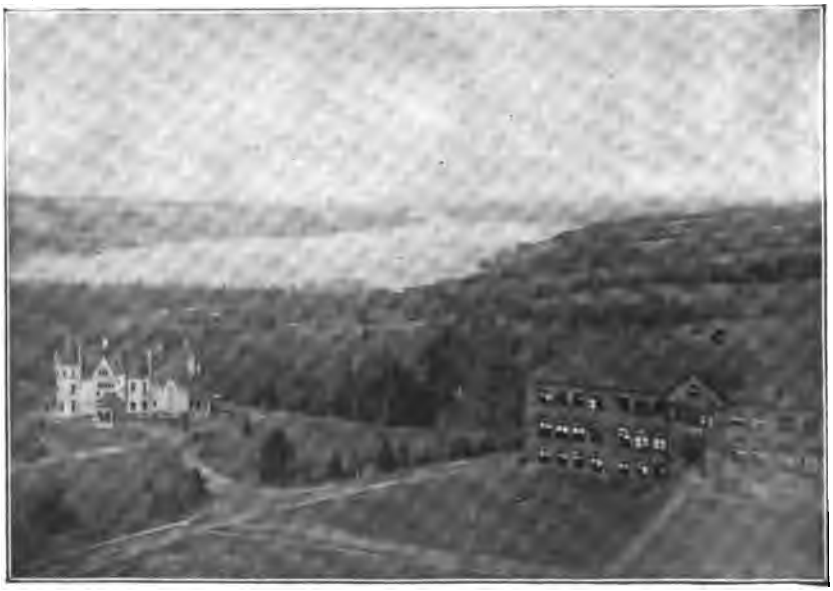

FIG. 96. View of the Lake Cayuga Valley from the Cornell Campus. A broad preglacial stream valley broadened and deepened by glacial erosion and now occupied by a lake.

bottoms of the preglacial valleys of these tributary streams are not now below the level of the lake water in the southern part of the valley. If all the drift could be removed and the streams be allowed to flow along the line of the course of the preglacial valleys, and enter the valley of Lake Cayuga as it now stands, excepting that it be robbed of water, they would tumble between three and four hundred feet in a distance of about a mile, commencing their sudden descent near the present lake margin, a most unnatural condition for mature tributaries near their mouth.

Another fact in support of this explanation, clearly seen since the paper referred to was published, is that, if the main Cayuga stream flowed at the level of the present lake bottom, some of the tributary streams, like Fall Creek, must now have a drift-filling of not less than a thousand feet at a distance of three miles from the lake, a depth of drift hardly to be expected, and greater than anything anywhere known.

THE MOHAWK RIVER.[1]—Very early, possibly as far back as the paleozoic times, the Adirondack Mountain mass evidently stood as a highland area, shedding water in several directions, and perhaps radially in all directions, as it does now. Some of these streams, flowing northward and westward, entered the "Laurentian River," whose course determined the location of the Ontario Valley.

Judging from the geological history of the region, it seems exceedingly improbable that the Mohawk then had the course which it now follows. There are various reasons for believing that this river has developed its present course only after a long and complex history. It stands now as a notable topographic feature, a trench in the land in places over fifteen hundred feet deep and from twelve to twenty miles wide.[2] And it offers some evidence of its early history.

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[1] Vanuxem, Geol. of New York, 3d Dist., 1842, 20–21; 203–211; Dana, Amer. Journ. Sci., Ser.II, XXXV, 1863, 243–249; Darton, New York State Museum Report, 47, 1894, 603–623; same, Report 48, Part 2, 1895, 33–53; same, Geol. Survey New York, 14th Annual Report, 1896, 33–56; and, particularly, Brigham, Bull. Geol. Soc. Amer., IX, 1898, 183–210.

[2] Brigham, Bull. Geol. Soc. Amer., IX, 1898, 183–210.

According to Brigham,[1] the original Mohawk located itself on the southern side of the Adirondack Mountain mass, eating westward by headwater erosion as far as Little Falls. It was essentially a monoclinal valley, following the boundary between the Paleozoic and massive Archean rocks. Another river, flowing westward and entering the Ontario Valley, and called by Brigham the Rome River, disputed with the Mohawk for territory at its headwaters near Little Falls.

The first evidence of this is found in the fact that the Mohawk narrows up to a gorge at Little Falls, somewhat as the Allegheny does at Thomson's Gap (p. 158), while west of this gorge the valley again broadens, indicating that Little Falls is a divide region. This was early suggested by Chamberlin[2] and has been confirmed by the careful studies of Brigham,[3] who points out that the divide was determined by faulting at Little Falls, as a result of which the more resistant rocks at this point were brought up nearer the surface than elsewhere in the valley. The proof that the ancient divide was here is so clearly suggested by the topography that it has occurred to many travelers in passing through the Mohawk on the railroad. In addition to the topographic evidence there is proof similar to that brought forward by Carll for the Upper Allegheny (p. 159), namely, well-borings showing that the rock valley bottom west of Little Falls slopes westward, although the stream itself is now flowing eastward upon drift deposits. The rock floor slopes from an elevation of 376 feet at Little Falls to 347 at Utica and 220 at Sylvan Beach on Oneida Lake. The drift-filling is frequently more than 150 feet.

The Little Falls divide was lowered somewhat by glacial erosion, and then by the glacial water at the time when the Great Lakes were forced to overflow through the Mohawk Valley. At that time, while the divide was being lowered by water action, the headwaters of the present Mohawk were being filled with sand and gravel, since they were occupied by lake waters with an overflow at Little Falls. The old divide has been still further lowered by the postglacial cutting of the western stream, which was added to the original preglacial Mohawk.

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[1] Bull. Geol. Soc. Amer., IX, 1898, 186.

[2] Third Ann. Rept. U. S. Geol. Survey, 362.

[3] Bull. Geol. Soc. Amer., IX, 1898, 183–210.

According to this interpretation, the proof of which seems complete, the falls and rapids of the Mohawk, which have been so important in determining the sites of towns and industries, have been caused, first, by the production of faults, probably at the time of the Appalachian uplift, which raised the harder underlying rocks, so that they have served as a divide because of their greater power of resistance; and, secondly, by the influence of the glacier in combining two streams flowing in opposite directions into a single river, the present Mohawk, causing the upper part to flow across the old divide. This glacial accident has had an important influence upon the entire history of New York State, for, by building up the present grade of the Mohawk, it made the project of the construction of the Erie Canal far more feasible and less expensive than it would have been had it been necessary to *rise over* the divide at Little Falls, instead of *passing down* a fairly uniform and moderate slope, mostly over soft glacial and lacustrine, and possibly, in part, marine deposits.[1]

THE HUDSON RIVER.—The Hudson is divisible into two quite different parts: (1) the navigable section, from its mouth to Troy, which is in reality an estuary reached by tide-water, and (2) the section upstream from tide-water, where it is a small but normal river, often interrupted by falls and rapids. In these respects the Hudson is like all the rivers that enter the ocean in the northeastern part of the continent, excepting that, in the case of the Hudson, the estuarine part is relatively longer and narrower than in the case of most such streams.

It takes but little study of this and other similar valleys to see that the upstream portion, above the tidal section, is the same in origin as the part occupied by the tide.

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[1] Taylor, Amer. Geol., IX, 1892, 344; Upham, same, 410.

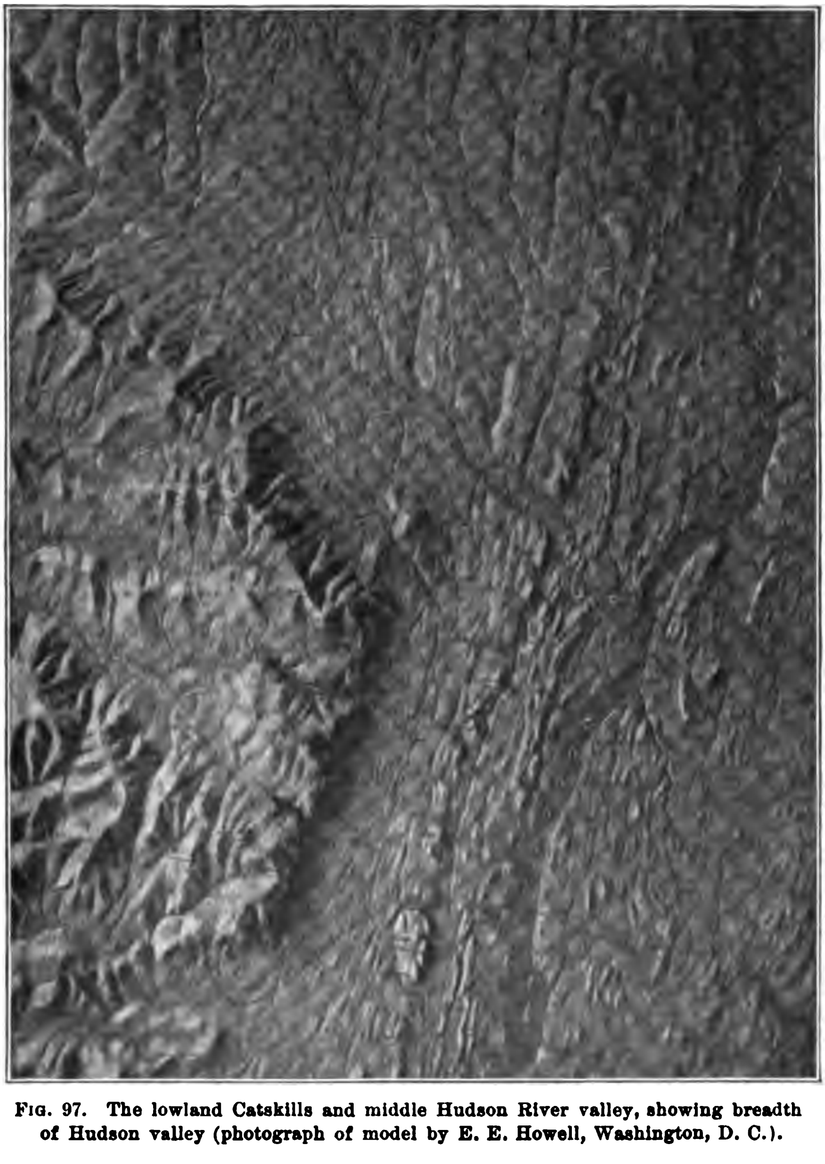

Fig. 97. The lowland Catskills and middle Hudson River valley, showing breadth of Hudson valley (photograph of model by E. E. Howell, Washington, D. C.).

They are in both cases valleys of erosion, and the occupation of a part of the valley by the tide water is due merely to the sinking of the land which has allowed the sea to enter the valley, as it would enter any land valley of the present if the land level should sink far enough. The valley has been partly drowned, and the river may be said to be a drowned river near its mouth. There is other evidence than that of the land topography that this is the true explanation.

At what period the Hudson River began its course is not certain. It now cuts across formations of different kinds, some of them representing the very roots of planed-down mountains, formed as far back as the Silurian time (p. 24). It is evident that the river did not originally have such a course as to have allowed it to cut diagonally across these mountain chains. Professor Davis[1] believes that the Hudson valley lowland, which lies on either side of the narrow trench now occupied by the river, was excavated during the Tertiary times, being begun upon a broad peneplain of Juratrias-Cretaceous origin, and hence having its course determined by the irregularities of this plain, rather than by the attitude of the markedly folded rocks out of which the peneplain had been formed by long denudation.

An alternative view is that a broad lowland which had been formed here in the course of time was then submerged beneath the sea, either in Triassic or Cretaceous times, and later, being raised to form dry land, was occupied by a river whose course was determined by the deposits made in the arm of the sea. Such a river course, which would be said to be a superimposed course, would not necessarily be in accord with the attitude of the rocks, but might readily cross mountain folds. No proof of either of these hypotheses has been brought forward, and they therefore can be offered merely as suggestions as to the possible cause for the present location of the Hudson; and it should be stated, furthermore, that these two suggestions do not exhaust the number of possible hypotheses.

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[1] Proc. Boston Soc. Nat. Hist., XXV, 1892, 318–335.

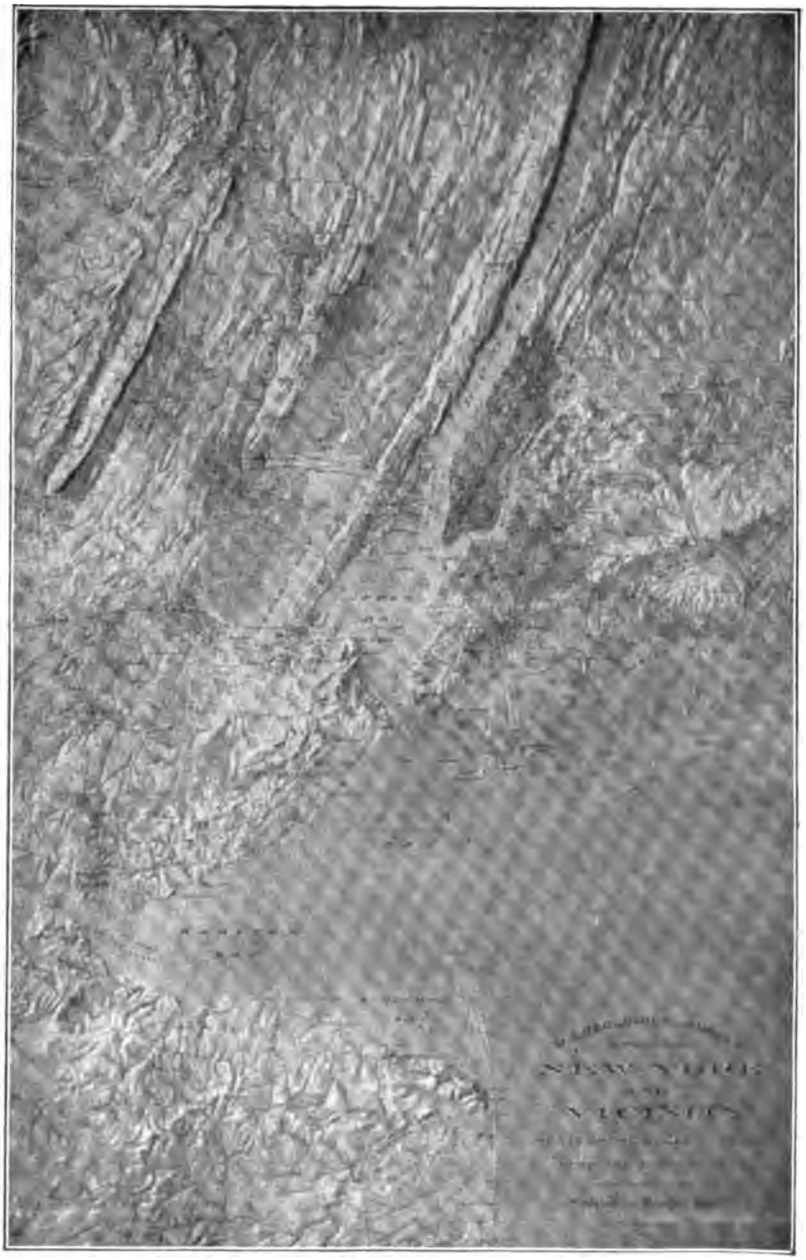

FIG. 98. Model (by E. E. Howell) of lower Hudson Valley and New York Bay.

Whatever the origin of this peculiar course, the Hudson seems to have begun the formation of the prominent features of its present valley in the Tertiary time, when the land was uplifted before the glacial period. Since this uplift was greater in the north than in the south, the valley was cut more deeply in the north; and where the rocks are soft, as above Newburgh, the valley is wide, while where they are harder it is narrow.[1] As a result of late Tertiary, or possibly post-Tertiary, uplift and erosion, the river has cut a trench in its lowland a mile or more in width and of unknown depth. This trench, or gorge, is the valley of the Hudson which one sees in passing up the river; but to see its real relation to the broader valley one must leave the gorge and look across the valley from the high ground at one side, as, for instance, from the eastern slopes of the Catskills (Fig. 97). The Hudson Valley is then seen to be a double valley, very broad and gently sloping for the most part, and traversed by a narrow trench cut in the bottom of the broad valley lowland.

This inner, later gorge valley of the Hudson is of marked interest. It is up this that the tidewater extends, and therefore its bottom is now below sea-level. Since the gorge is the result of carving by river water, it is evident that the river trench was cut at a time when the land was higher above sea-level than at present. This being so, one would expect to find a continuation of the valley beyond the present coast line along the sea-bottom plain of the continental shelf. As has been shown by Lindenkohl,[2] there is a channel extending to a distance of 105 miles from New York, having a width of a mile or two and a depth of 2,400 feet. It reaches to the very edge of the continental shelf, where it is indicated by a deep and rather narrow gorge. There are similar drowned river valleys off the New England coast, and near the mouth of the St. Lawrence, indicating a former general elevation of the northeastern part of the continent.

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[1] These statements are based upon Professor Davis' discussion of the valley, Proc. Boston Soc. Nat. Hist., XXV, 1892, 318–335. See also Davis, Bull. Geol. Soc. Amer., II, 1891, 570–571.

[2] United States Coast Survey, Annual Rept. for 1884, 435–438 (this channel is mentioned by Newberry, Annals New York Lyceum Nat. Hist., IX, 1870, 221; and also Popular Sci. Monthly, XIII, 1878, 641–666); same, Amer. Journ. Sci., Ser. III, XXIX, 1885, 475–480; same, XLI, 1891, 489–499; Dana, Amer. Journ. Sci. Ser., III, XL, 1890, 425-437; Upham, Bull. Geol. Soc. Amer., I, 1890. 563–567; same, Proc. Amer. Assoc. Adv. Sci., XLI, 1892, 171–173.

During the time of the formation of this submerged valley, the Hudson must have received as tributaries some of the rivers of New Jersey and Connecticut which now enter the sea independently, and it may possibly have received the Connecticut itself. So the drowning of a portion of the land has dissected a stream system in its lower portion.

During the glacial period, the broad Hudson valley lowland was scoured by ice erosion, for it formed a trough down which the ice could easily move. Also, when the ice left the region, the land stood lower than at present, and the sea extended through the Hudson to the St. Lawrence by way of the Lake Champlain Valley, thus making New England an island. The evidence of this is abundant and conclusive, for the valleys of the St. Lawrence, Lake Champlain, and the Hudson, contain clay deposits, often bearing marine fossils; and there are river deltas on the valley sides opposite the mouths of the streams.[1] The sea reached up the valley of the Mohawk, and some think that it passed even over the divide at Little Falls, as far as Lake Ontario, making the Adirondacks also an island. In some parts of the valley the deposits do not contain marine fossils; but this cannot be taken as evidence against marine origin, for the water may well have been freshened by the addition of large quantities of ice-furnished water.

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[1] Hale, Amer. Journ. Sci., III, 1821, 72–73; Finch, same, X, 1826, 227–29; Mather, Geol. of New York, 1st Dist., 1843, 129–150; Emmons, same, 2d Dist., 1842, 422–427; Ramsay, Quart. Journ. Geol. Soc., XV, 1859, 211–212; Hitchcock, Geol. of Vermont, Vol. I, 1861, 152–191; same, Proc. Amer. Assoc. Adv. Sci., XIX, 1870, 175–181; Dwight, Trans. Vassar Bros. Inst., III, 1884–5, 86–97; Merrill, Amer. Journ. Sci., Ser. III, XLI, 460–466; Davis, Proc. Boston Soc. Nat. Hist., XXV, 1891–92, 318–335; Ries, 10th Rept. New York Geological Survey, 1890, 110–155; same, Trans. New York Acad. Sci., XI, 1891, 33–39; Turner, Bull. Phil. Soc. of Washington, XI, 1891, 385–410; Taylor, Amer. Geol., IX, 1892, 344; Upham, same, 410; Darton, New York State Museum Report, 47, 1894, 453–455; Nason, same, 459–468; Brigham, Bull. Geol. Soc. Amer., IX, 1898, 183–210.

According to Merrill, the depression was greater in the north than in the south, amounting to 340 feet near Albany, and about 80 feet near New York; and this conclusion is in harmony with the evidence from other sections of the country. The reasons for the difference in elevation of the beaches and deltas of the Hudson Valley, as elsewhere on the continent, is that the postglacial uplift which has raised the deposits above the sea has been greater in the north than in the south.

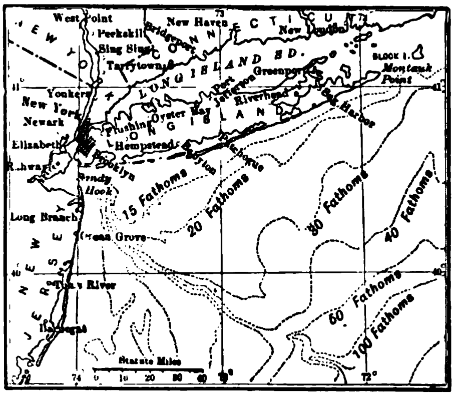

Fig. 99. Map of submerged Hudson River Valley on coastal shelf off New York (after Dana).

Other Rivers.—Little else has been written about the rivers of New York; but there are some points of interest in the articles mentioned below. Emmons[1] describes Glens Falls, and, in the same report, briefly discusses other rivers in his district, as do also Hall, Vanuxem and Mather in their reports on the geology of New York State. An interesting case of glacial diversion in the Bronx River is described by Kemp,[2] who has also explained some of the valleys of the Adirondacks.[3]

As shown by Darton,[4] the headwaters of the Kaaters Kill and Plaaters Kill in the Catskills are exceedingly peculiar. The tributaries enter in barbed fashion, pointing up stream, instead of down stream, as they should normally. It looks as if they were tributaries to a west-flowing stream, instead of an east-flowing one; and Darton's suggestion is that they originally did flow westward into a stream which the Kaaters Kill and Plaaters Kill have been beheading by headwater erosion. This river capture of headwaters may well be expected here, for the Kaaters Kill and Plaaters Kill have steep, short slopes to tidewater, while the streams with which they are in combat have a longer and less steep slope. It is one of the best cases of headwater conquest so far presented.

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[1] Emmons, Geol. of New York, 2nd Dist., 1842, 188.

[2] Trans. New York Acad. Sci., 1896, 18. See also Britton, Trans. New York Acad. Sci., I, 1882, 181–183, and Brigham, Amer. Geol., XXI, 1898, 219–222.

[3] Bull. Geol. Soc. Amer., VIII, 1892, 408–413.

[4] Bull. Geol. Soc. Amer., VII, 1896, 505–507. See also Julien, Trans. New York Acad. Sci., I, 1881, 24–27.

Lewis[1] points out that the short streams on the southern side of the Long Island moraine, where they flow over the overwash gravel plains, have steep banks on the western side and flow in a direction slightly south of west. A similar condition has been shown to exist elsewhere where rivers are flowing in shallow trenches which they have cut in soft deposits, and the peculiarity has been explained by the deflective effect of the earth's rotation, which, in the northern hemisphere, tends to turn moving bodies to the right. Lewis applies his explanation to the courses of the Long Island streams, and Gilbert,[2] after considering the question, accepts Lewis' explanation.

CAVERNS.—During the course of stream development, in a region of limestone rocks, some of the drainage, finding its way underground, dissolves the limestone and carves underground channels, which in some cases become true underground streams, possibly miles in length. Nowhere in New York is the development of limestone beds sufficiently great for the formation of extensive underground courses; but there are some limestone beds, and in these one would expect to find such drainage.

The caverns so formed are naturally superficial, for the flow of water in them is determined by the level of the outflow, which itself is governed by the surface streams. Naturally, then, some of the underground channels have been destroyed by erosion in the glaciated region. Others have no doubt had their inlets or places of outflow clogged with drift, so that they are not easily seen; and still others, as in any limestone region, have not yet been discovered. But a few such underground channels, such as Howe's Cave, have been found and are visited.[1] They are not highly ornamented by stalactites and stalagmites, and do not compare in importance with the caves in other regions of the United States, where limestone strata are extensively developed. In the limestone regions of New York there are numerous springs, some of them of large size and marked permanence, coming, undoubtedly, from underground channels — in other words, caverns.

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[1] Amer. Journ. Sci., Ser. III, XIII, 1877, 215–216.

[2] Amer. Journ. Sci., Ser. III, XXVII, 1884, 427–432.

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[1] See, for instance, Shepard, Amer. Journ. Sci., XXVII, 1835, 368–370; Gebhard, same, XXVIII, 1835, 172–177; Mather, Geol. of New York, 1st Dist., 1843, 109–113, 637; Eggleston, Amer. Journ. Sci., Ser. II, I, 1846, 434–435.

CHAPTER VI

LAKES AND SWAMPS

ORIGIN.—A lake may be defined as a basin-shaped depression on the land, more or less completely filled with water. A depression along the seashore, and partly connected with the ocean, is not commonly considered a lake, though when disconnected by the growth of a sandbar, such a body of water is often, and very properly, known as a pond or lake. Between pond and lake neither a popular nor a scientific distinction can be drawn, though, speaking very generally, the smaller bodies are ponds, the larger lakes.

A basin-shaped depression in the land surface is not a common production of the action of running water alone, although small basins of this origin are actually produced. For instance, a stream flowing over soluble rock, as limestone, very frequently dissolves tiny basins in that part of the stream-bed where the rock material is most soluble. Again, the water at the base of a cataract frequently excavates a basin in which a deep pool stands, and this, with a change in direction of the river, or its removal for any other cause, may become a pond. (See p. 206.)

Speaking generally, and bearing in mind such minor exceptions as these, it may be said that lake basins are rarely carved by the water that occupies them. Nevertheless, lakes may be considered to be parts of rivers where locally, for some cause, the normal slope of the river-bed has been changed to a concave surface. There is such an exceedingly complex series of causes for these basins that at first thought they would seem to defy an attempt at classification. One of the best attempts at such a classification is that by Davis,[1] in which origin is used as a basis. In his paper the general subject of the origin of lakes is discussed, and numerous instances cited for the various classes. In a later note[1] Davis proposed to substitute another basis for lake classification, considering them as parts of rivers changed to basins either as a result of accident or in the course of normal river development. It is that idea of Professor Davis which is followed in this brief consideration of New York lakes.[2]

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[1] Proc. Boston Soc. Nat. Hist., XXI, 1880–82, 315–381.

ORIGINAL CONSEQUENT LAKES.—On any *new land* surface, of whatever origin, basin-shaped depressions may exist. If the water supply were sufficient, lakes would fill the depressions, and these, being consequent on the initial or original topography, may be called *original consequent lakes.* For instance, the deposits that are now being made upon the sea-bottom are not being laid down with perfect uniformity, so that numerous basins exist there. Illustrations of such basins are found in large numbers in the lakes of the Florida Everglades region,[3] which is a raised sea-bottom. There are now no instances of this class in New York, though when the plains were raised at the close of the Paleozoic, there must have been such depressions.

Very similar to these basins are those formed on the beds of lakes by irregularity of the sediment deposit. When for any reason the lake waters recede, these basins become independent lakes. There is a rim of old lake-bottom around the shores of Lakes Erie and Ontario, in which there are numerous ponds and lakes, some of which doubtless occupy original consequent basins in the constructional lake-bottom topography.

A surface constructed by any other means may possess original irregularities. For example, the surface of a lava-flow may be irregular, though of *this* class no examples would be expected in New York. They abound, however, in regions where lava-flows have recently occurred. Ponds not uncommonly gather in the crater-shaped depressions amidst the sand-dunes, as along the Long Island shore. We find abundant illustrations of original consequent lakes in the depressions existing in beds of till, or moraine, or stratified gravel,[1] or other deposits which have resulted directly or indirectly from the glacial invasion. Still another class of original consequent lake is that which must have existed on the surface of the ice itself when it covered the State. These temporary ice-surface lakes are common on the Greenland ice-sheet to-day.

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[1] Science, X, 1887, 142.

[2] For an excellent discussion of lakes see Russell, Lakes of North America, Ginn & Co., 1895.

[3] This is one interpretation of the Florida lakes and swamps; another is that they are sink-holes caused by solution of limestone. In all probability both explanations apply in different cases.

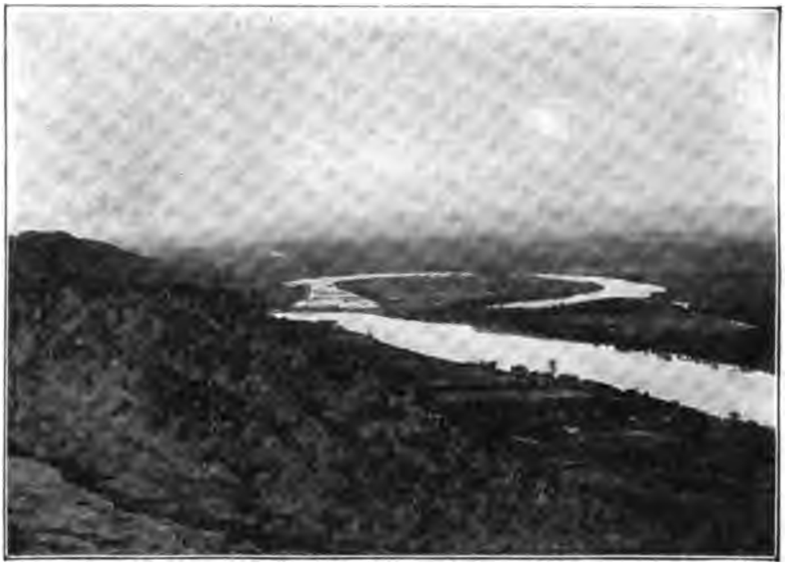

FIG. 102. Ox-bow-cut-off Lake in Connecticut Valley, Northampton, Mass.

LAKES OF NORMAL DEVELOPMENT.—By these are meant the lakes which are formed in the course and as the result of the normal development of rivers. Two instances of these have been mentioned above (p. 193); and another, similar to them because of its direct relation to the existing stream-bed, is the tiny basin so often caused by irregularity of *deposit* in the stream-bed. One sees these particularly well illustrated in semi-arid regions, as in central Texas, where, during the dry season, the stream-bed becomes transformed to a series of dry bars with ponds between. So marked is this feature that it has come to be symbolized on the topographic maps, where such intermittent streams are marked by a dotted line.

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[1] Fairchild. Journ. Geol., VI, 1898, 589–596.

A larger illustration of lakes of normal development may be found upon floodplains. Such a plain is the direct result of the normal development of a river, and in the course of its formation the stream that builds it meanders about over it, frequently abandoning one curve and commencing another. Thus a new channel is carved in the floodplain, while the old channel, being separated from the main stream by river floodplain deposit, then becomes a true lake. Such lakes are strikingly developed on the Mississippi River floodplain (Figs. 100 and 101), where, in some cases, they have the shape of perfect meanders or ox-bow curves. When cut off by a change in the river, they are known as ox-bow-cut-off lakes (Fig. 102). On the floodplains of many of the large and small streams in New York this class of lake is well illustrated by linear ponds in which all stages of separation from the main stream are illustrated.

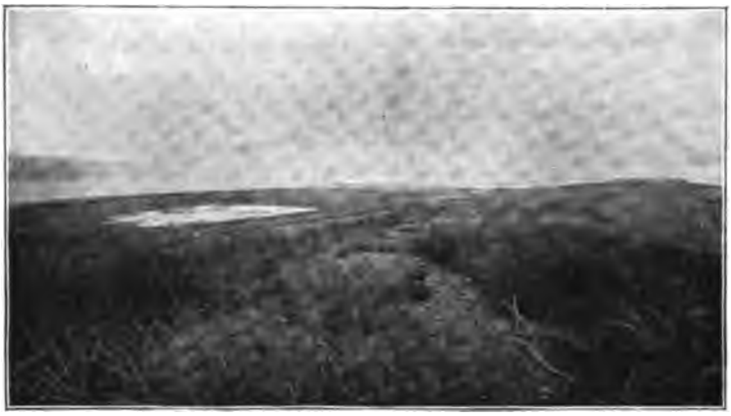

FIG. 103. Pond formed by irregular growth of a delta, Ludlowville, N. Y. (C. S. Downes, photographer).

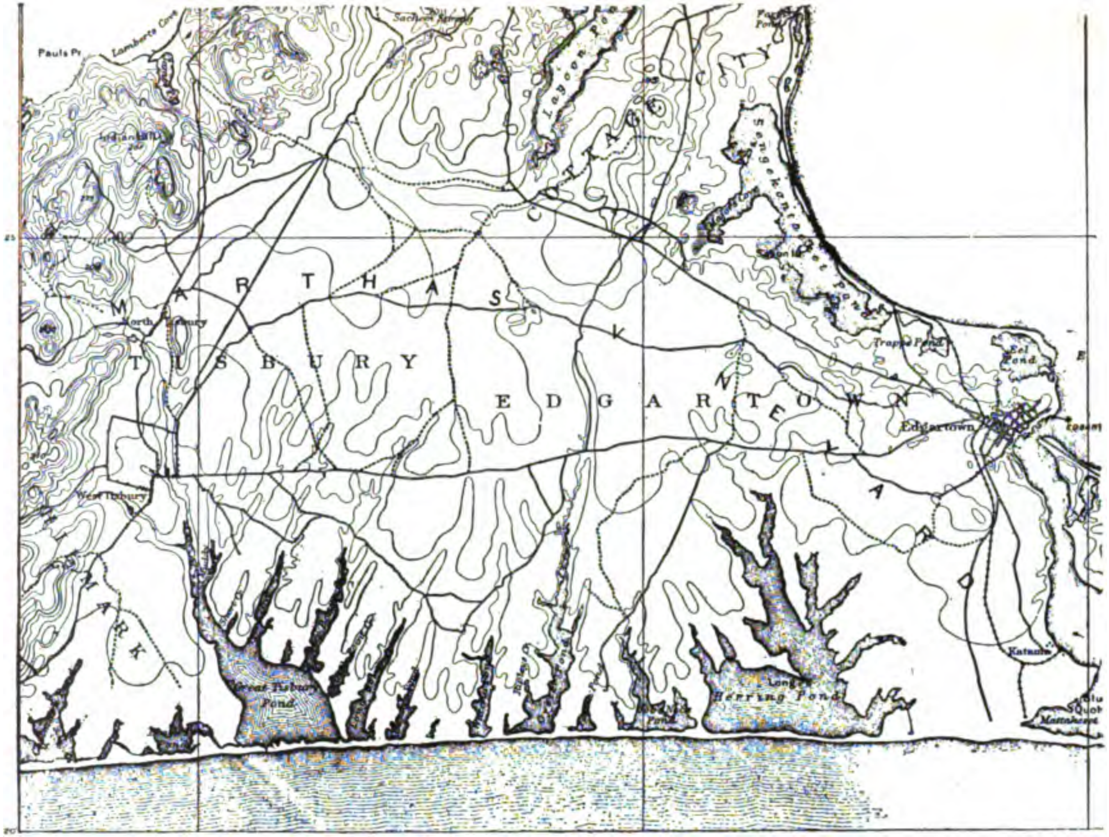

FIG. 104. Ponds formed by sand bars across the mouth of bays, Martha's Vineyard, Mass. (United States Geological Survey Topographic Map).

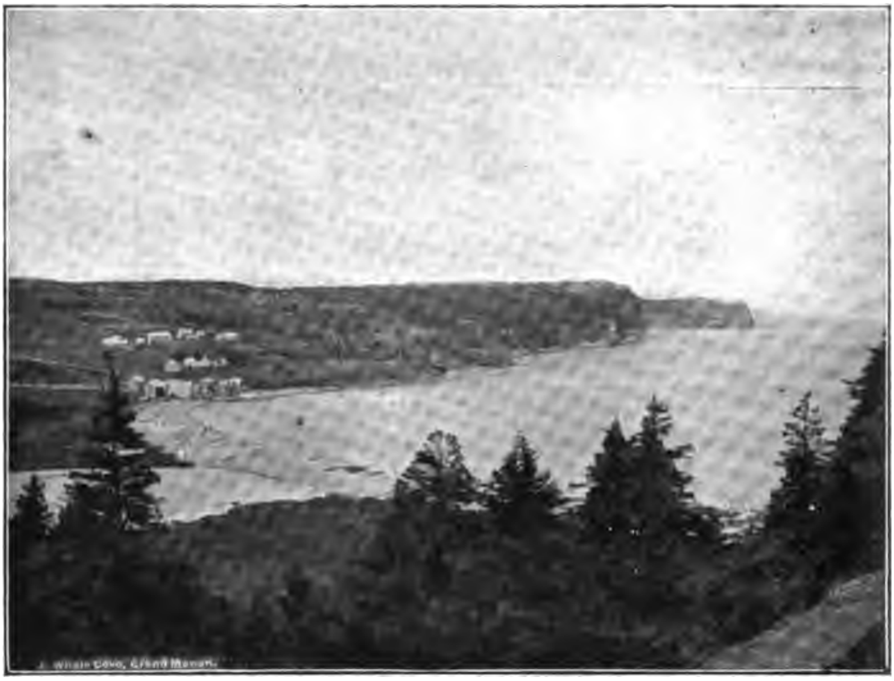

Fig. 105. A bar shutting in a pond, Grand Manan.

Where streams have built deltas the irregular growth of the delta front, combined with the action of waves, often forms ponds or lakes. These are admirably illustrated on the growing Mississippi Delta by some of the large lakes which are entirely inclosed, and by some of the arms of the sea which are partly inclosed. The same cause operates in the growth of lake deltas, and ponds of this type are common on the deltas which are being built in the New York lakes (Fig. 103).

By the steady deposit of sediment in river courses, lakes and lake-like expanses may be often caused. As an instance, the Mississippi River, above the mouth of the Chippewa River, is transformed to a quiet body of water known as Lake Pepin. This quiet stretch, which is *called* a lake, is the result of a partial dam built from the sediment brought down by the Chippewa and deposited in the current of the Mississippi, which was unable to carry it further. Tiny illustrations of this same condition are found in New York.

The growth of sand- and gravel-bars across bays at the mouths of small streams often transforms them to true lakes. One may see numerous illustrations of this along the shores of Lakes Ontario and Erie, and also along the Long Island coast. Here there is every gradation between the open bay and the lake due to the complete closure of the bay by sandbars (Figs. 104 and 105).

In the course of the normal development of certain streams that are peculiarly located, the drainage may become underground (p. 191). This is particularly liable to be the case in limestone regions where the water dissolves an underground channel for itself. In places the solution causes a settling of the surface, forming sink-holes (Fig. 106) in which lakes often gather (Fig. 107). The removal of any soluble substance, as salt, may cause the same kind of basin. While lake basins of solution origin are very common in places, few have been discovered in New York. There are illustrations of this class of basin near Union Springs on the shore of Lake Cayuga.

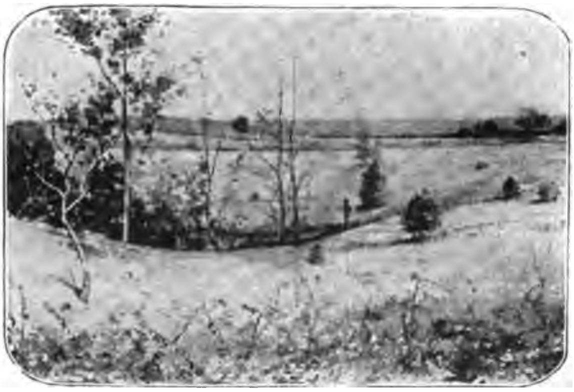

FIG. 106. A sink hole in the limestone region of Kentucky.

LAKES DUE TO ACCIDENT.—One of the most common ways in which river slopes have been locally changed to basins is by the development of a dam across a river

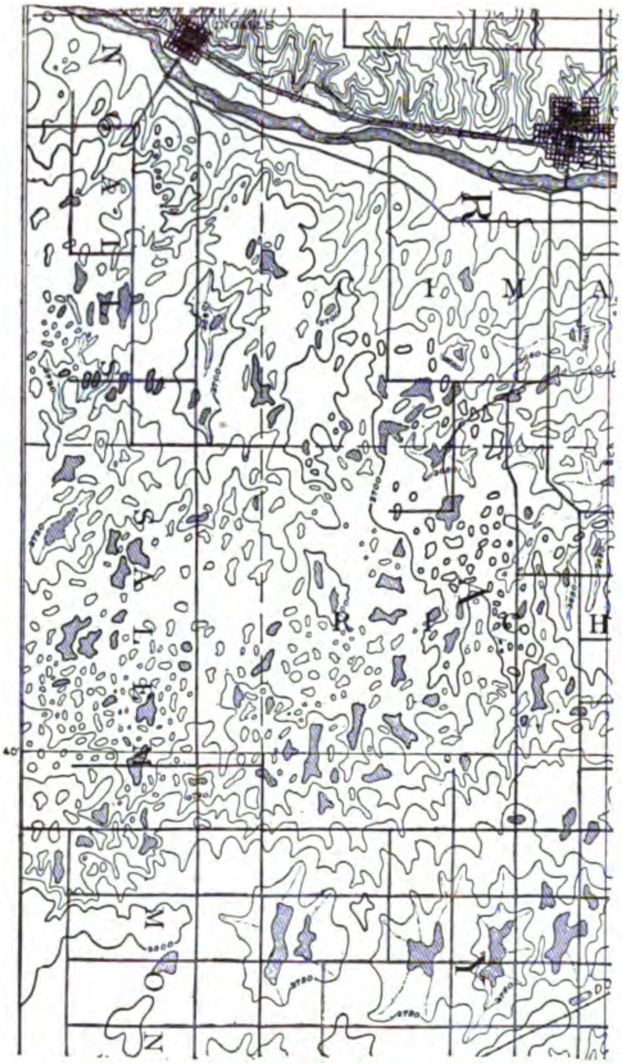

Fig. 107. Ponds in sink-holes near Dodge City, Kansas (United States Geological Survey, Dodge sheet).

course. Such dams are commonly due to some accident by which the normal development of the river has been interrupted. For instance, the early settlers of New York found hundreds of these ponds and swamps caused by the dams thrown across small streams by beavers. Some of these still exist, and in parts of the continent, as in Canada and the Rocky Mountains, these interesting animals are even at present building their dams.

A landslide or an avalanche may obstruct a stream course and transform it to a lake. Among lofty mountains, as in the Alps or Himalayas, vast dams of fallen rock have formed good-sized lakes, and in New York there are also instances of the same kind of basin, though very much smaller.[1] Many of the landslip dams of New York have been formed where a stream, eating at the base of a bank of glacial till, has caused a slide to occur, which has temporarily transformed the stream to a pond above the dam.

The movement of the earth's crust during mountain building oftentimes throws insurmountable barriers across stream courses. As a mountain chain rises higher and higher, it may so interfere with the drainage as to turn the streams far out of their original courses. Among mountains of recent growth, lake basins due to this cause have been discovered, and still other illustrations are found in basins that have been drained. Doubtless lakes of this sort developed in the course of the formation of the mountains of eastern New York; but this was so long ago, and has been succeeded by such a complex series of changes, that every evidence of their existence has been erased.

To form lake basins by crustal movement does not necessarily call for the growth of a mountain chain; a gentle warping of the crust may cause a broad hollow. Also, with a stream sloping moderately in a given direction, let us suppose northward, an elevation or tilting of the land, slightly greater in the north than in the south, may transform the stream valley to a lake basin. It seems certain that such lakes as Champlain and the Great Lakes owe at least a part of their present basin form to great crustal movements, of which there is excellent evidence.

But by far the greater number of the thousands of lakes dotting the surface of New York, and northeastern America in general, have come into existence as the result of glacial accidents. In numerous ways the ice has been responsible for lakes. For instance, when the ice was withdrawing from New York, it obstructed and dammed most of the north-flowing streams (p. 131). Since many of the New York streams are north-flowing, this caused the development of numerous temporary lakes held behind the ice dam. The evidence of these, in the form of shore lines and deltas clinging to the hillsides, is found in various parts of the State. Even in some of the south-flowing streams there is evidence of similar conditions; for, as in the case of the Alleghany, some streams that originally flowed northward, were held in the form of lakes for a long enough period to cut new channels at the outlet and thus reverse the streams. By far the most marked evidence of these glacial lakes is found around the shores of the Great Lakes (Chapter VIII), which were raised by ice dams until they covered large areas that are now dry land, and found outlets quite different from those at present occupied.

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[1] Mather, Geol. Survey New York, 1st Dist., 1843, 32–37; 634–636; Dwight, Amer. Journ. Sci., Ser. II, XLI, 1866, 12–15.

As the result of glacial *deposit*, scores of thousands of lakes have been caused in North America. Before the ice came, there existed valleys occupied by streams. These were then buried beneath the ice and more or less completely filled with glacial deposit, so that, instead of retaining the original regular slope of the preglacial valleys, the drift-filled valleys were frequently irregular, with numerous basins. In these, lakes, ponds and swamps now exist.

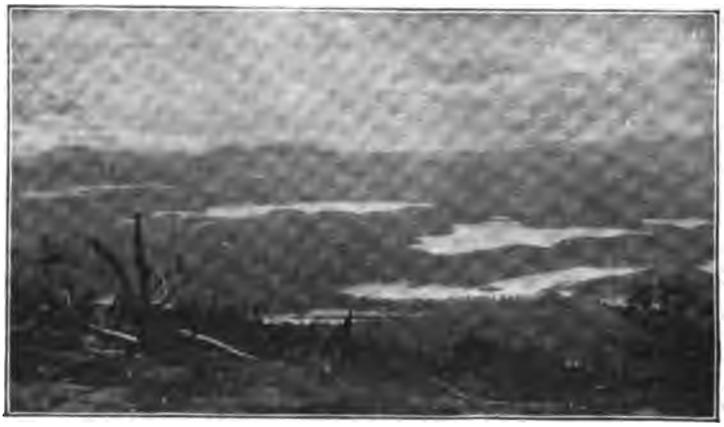

FIG. 108. A group of glacial lakes in the Adirondacks (S. R. Stoddard, photographer).

There are many different kinds of lakes resulting from glacial deposit. In some cases morainic dams have been built across streams. Again, the dams are drumlins, or eskers, or sandplains, or kames. As a result of some variation in supply, a greater load is deposited in one place than in another, and then of course a dam results.

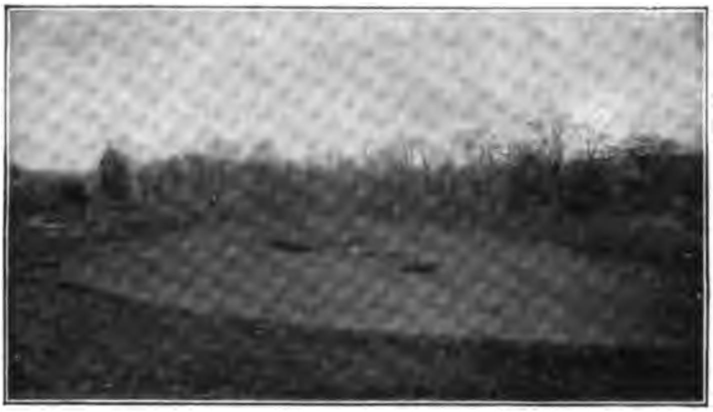

FIG. 109. Marl bed of a nearly dried-up pond in a kettle in the moraine near Cortland, N. Y. (C. S. Downes, photographer.)

There is an almost infinite variety of possibilities here, and even careful study in the field will not always discover the exact reason for such dams. To this class of lakes belong many of those that beautify the scenery of the Adirondacks[1] (Fig. 108).

As has been stated above (p. 195), in the irregularities of the glacial deposits themselves, which may be considered to constitute *new* land, numerous lakes of original consequent origin are found. The most abundant of these are the ponds in the morainic kettles (Figs. 64, 65 and 109); but very often kettles in the stratified drift deposits — the kames, sandplains and overwash plains — are also found occupied by such ponds. In these sections, however, there are far more basins than lakes, for frequently the basins have so small a drainage area to supply the water, or else are located upon so permeable a deposit of sand and gravel, into which the water readily sinks, that the basins cannot be filled to overflow (Fig. 109).

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[1] In a recently published paper, Kemp (Bull. 21, New York State Museum) proves that Lake Placid is held in by a moraine dam, while other smaller lakes near by are in kettles in the moraine.

Another way in which the ice has been responsible for lake basins is by the erosive action of the glacier itself. Running water will maintain a fairly uniform slope, because of its liquidity; but rigid ice does not follow exactly the same laws. Either where the rock is softer, or the erosive power of the ice greater, a glacier may locally excavate more rapidly than elsewhere, and thus form a lake basin due to glacial erosion. Of these basins numerous instances have been found among mountains and in Greenland, where they abound. Doubtless in the State of New York there are many basins which are either entirely or partly caused by this erosive action. It is my belief that the basins of Lakes Cayuga and Seneca, and probably also Ontario, are in part due to glacial erosion (see pp. 151 and 179).

SPECIFIC INSTANCES.—So little study has been given to the origin of New York lakes that in most cases it is possible to make only such general statements as those above.

The Great Lakes, about which so much has been written, are discussed in Chapters VII and VIII, so that for the present it will suffice to state that their origin is apparently complex. Pre-existing valleys have been dammed by glacial deposit; these valleys have in some cases been deepened by glacial erosion, and the lake form and depth have been essentially modified by the tilting of the land. It is quite generally agreed that these causes combine to account for the Great Lakes, although the relative importance of one or the other of the causes is not agreed upon.

Chautauqua Lake is very shallow and is partly filled by stream deposits; its outflow at present is toward the south. The depth of the drift-filling is not known, but, judging by the depth of the drift in other valleys in this section, it must be great. While it cannot be considered established, there is some topographic evidence in favor of the view that at least the northern end of the Chautauqua Valley was in preglacial times tributary to the Lake Erie Valley, the cause of the diversion being an extensive morainic deposit across this valley. There is a constriction of the valley near the middle of the lake, which suggests that this may have been the preglacial divide. If this view be true, Chautauqua Lake is made up of parts of two valleys, one north-sloping, the other south-sloping, and each dammed by heavy morainic accumulations.

In central New York are a series of linear lakes, mostly located in north-sloping valleys. The two largest of these are Cayuga and Seneca. Each of these Finger Lakes owes its existence in part to glacial deposit, and, in the case of all but Cayuga and Seneca, this cause seems to be the important one for the basins. Without doubt they have all been modified by postglacial uplift of the land, which was greater in the north than in the south. Since this tilting is definitely established, it may be considered proved that the form and depth of the lakes have been modified by this cause.

In the case of Lakes Seneca and Cayuga, however, evidence has been brought forward (p. 179) to show that they are in large measure due to glacial erosion; and future studies will doubtless discover other instances in which the same conclusion will be reached with reference to some of the lakes in the Adirondacks and in other parts of the State. There has been a prejudice against glacial erosion as an efficient means for carving rock basins, due, no doubt, in part to the extravagant claims made for this agency by Ramsay and his followers. Some even ignore the evidence brought forward in support of this explanation of lake basins; but when the final word has been written concerning the operation of ice in the erosion of basins, I predict that rock basin formation will be given a much more prominent position than many glacial geologists at present believe.

Aside from the Finger Lakes and Ontario (p. 151), the only other case that I am aware of in which glacial erosion is claimed as the cause for a lake in New York is that of Lake Mohonk (Fig. 110) in the Shawangunk Mountains, which Darton[1] ascribes in part to glacial deposit and in part, and probably preëminently, to glacial erosion.

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[1] New York State Museum Report, 47, 1894, 540–552.

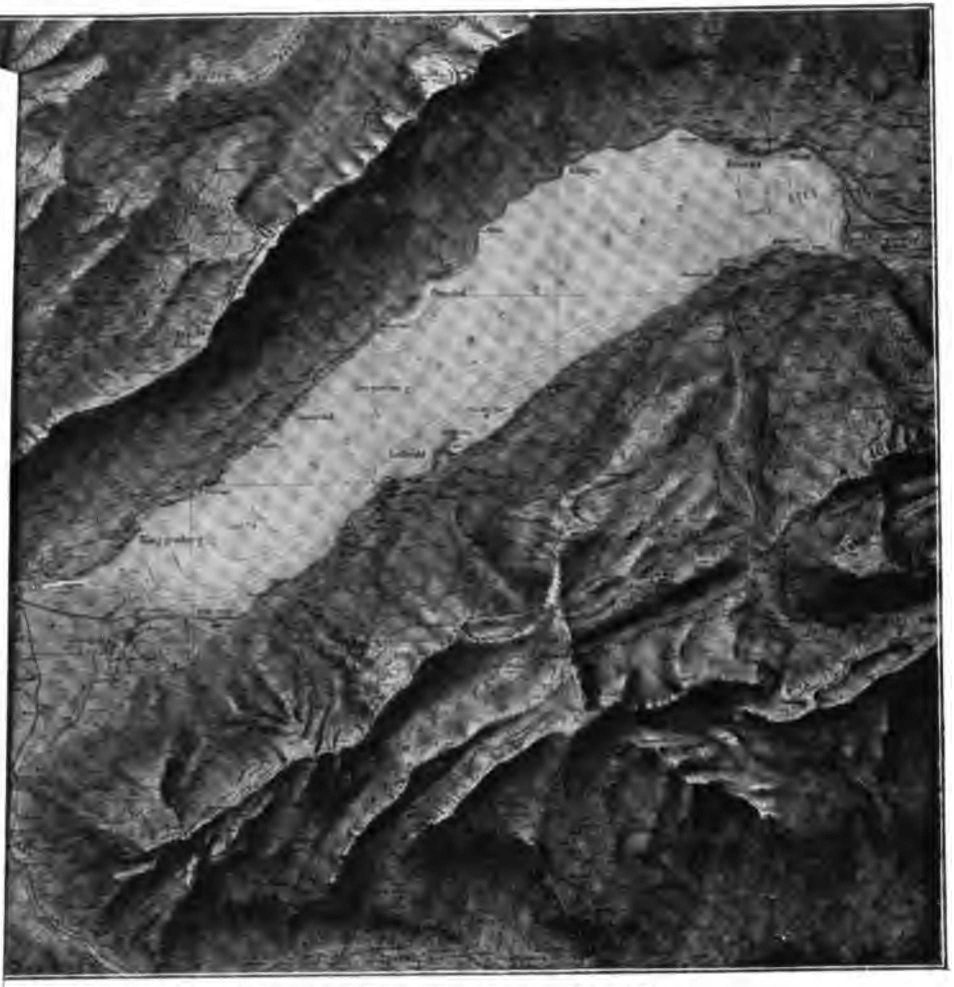
year may not be great, but after centuries and scores of centuries the cumulative effect of those minute contributions is felt.

Naturally most of the rock waste is furnished by the largest streams, and of this the coarsest, and in fact the greatest measure, is deposited at the very mouth of the streams, forming deltas which constantly grow out into the lake and will ultimately fill it, in combination with the other agents of filling (Figs. 103 and 114). A large stream bearing sediment from one side may build a delta which temporarily bisects the lake; or, as at Interlaken, in Switzerland, (Fig. 112), two such deltas from opposite sides may accomplish the same end. During the process of lake-filling there may be a great variety of stages.

The ultimate end, therefore, is destruction by filling, provided no other processes of destruction enter to check this. It may happen, to be sure, that the outlet stream cuts away the barrier faster than the lake is filled, and then the waters are drained off from the deltas and even from the lake bottom. This mode of destruction will generally occur only where the outlet barrier is a soft deposit, such as glacial till, that is easily removed. Even then there must be considerable slope for the outlet stream. Usually such an outflow stream possesses little power of erosion, because most of the sediment has been filtered out by the lake waters, and the stream therefore emerges clear and free from the cutting tools with which most streams are enabled to scour out channels even in hard rock.

If for any reason the power of the outlet stream becomes sufficiently concentrated, even though it has little sediment, it may work effectively to lower the barrier. For instance, Niagara River, which is scarcely cutting at all in its channel above the cataract, is at work at the Falls at such a rate that they have already retreated several miles, and are each year moving nearer Lake Erie. If they could ever be able to reach the lake, which, however, is not possible, a sudden drop in the lake level would then occur.

With the filling of a lake, vegetation often has much



owing bisection of lake by growth of Deltas (Swiss topographic map).

to do (Figs. 113–119). As soon as the water in one place becomes shallow enough, lacustrine vegetation takes root and in time transforms this section to a swamp. The delta margins are among the first to become thus transformed.

For instance, at the southern or inlet ends of Lakes Cayuga and Seneca, as well as of some of the other Finger Lakes, extensive delta deposits have been accumulated from the waste obtained in the erosion of the postglacial gorges. The depth of the delta-filling in some cases amounts to 200 to 300 feet, and the surface is nearly level, because it is primarily determined by the plane of the lake surface. These level tracts, reaching slightly above the water, are naturally swampy, particularly near the lake shore, and the same is true of some of the small deltas that are being built along the margin of these lakes opposite the gorges, as, for example, opposite Taughannock, on the shores of Lake Cayuga. These marginal delta swamps are not so extensive in Lake Cayuga as they are along

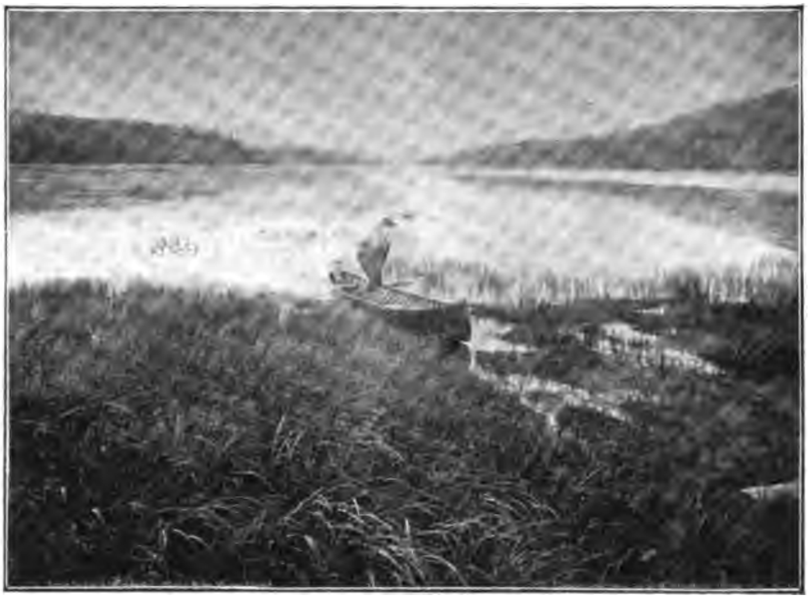


Fig. 113. Swampy shore of Long Lake, Adirondacks (Copyright, 1888, by S. R. Stoddard, Glens Falls, N. Y.).

the shores of Chautauqua Lake, because the depth of water to be filled is much greater in Cayuga than in the shallow Chautauqua. Opposite the mouths of all the larger streams entering Chautauqua Lake there are broad and very swampy delta tracts.

The delta plains near the head of Lakes Cayuga and Seneca are most swampy on the side where the sediment supply is least abundant, that is, on the western side in the case of Cayuga, and on the eastern side in the case of Seneca. This has had an important influence in determining the location of the two towns of Ithaca and Watkins (Figs. 96 and 114; also, p. 81).

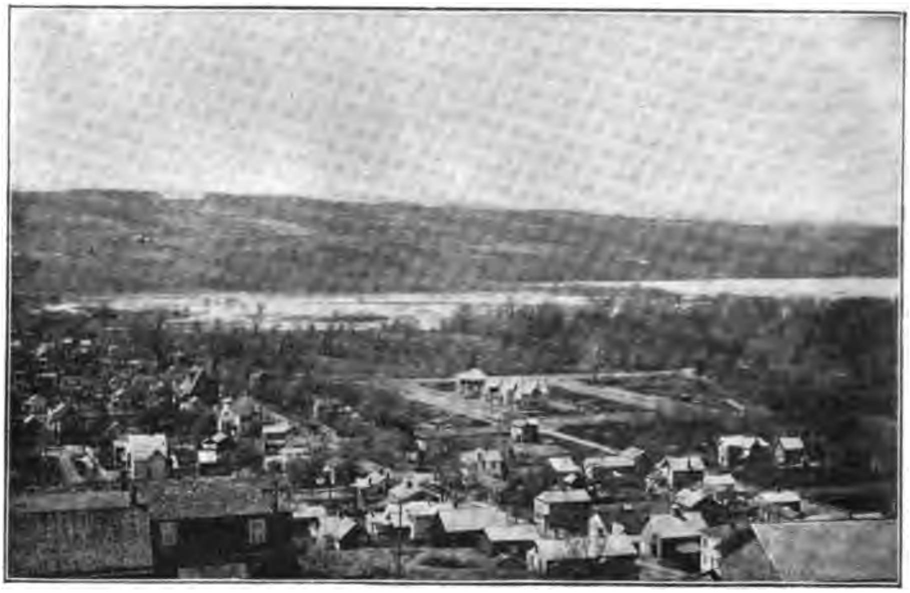


FIG. 114. Temporarily flooded western portion of Inlet delta at head of Cayuga Lake, New York.

Accumulation of rock débris in the lake will in time do more than form deltas opposite the stream mouths. It will eventually fill up the lake.[1] This filling is aided in its last stages by vegetation. The reeds, the lily pads, the sphagnum moss, and other water-loving plants, transform the shores to swamps, and finally may reach over the entire surface, forming a broad swamp in place of the lake (Fig. 119), at first not dry enough for trees, but later transformed to a tree-covered swamp. In these swamps peat is formed,[1] and there are thousands of filled ponds and lakes of this origin in the State.

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[1] Smyth, Amer. Geol., XI, 1893, 85–90.

In some cases, before the vegetable deposit is formed in excess, there are conditions favoring the accumulation of layers of animal remains. First sediment finds its way into the pond freely, then when the shores become swampy, the sediment is commonly arrested in its course near the margin, so that the shells of animals may accumulate more rapidly than either the rock fragments or the vegetable remains. In such a case layers of shells are formed, and after this, with the encroachment of vegetation, plant remains accu-

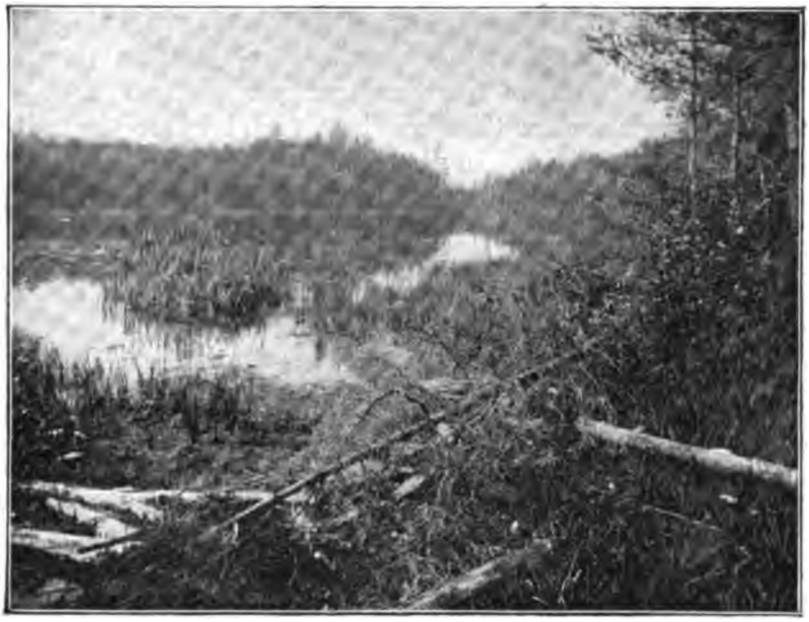

FIG. 115. Swampy shore of Fifth Lake, Fulton chain, Adirondacks (S. R. Stoddard, photographer).

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[1] Mather, Geol. of New York, 1st Dist., 1843; 12-16; 229-32; Vanuxem, same, 3d Dist., 1842, 229-31.

mulate in excess. In such places we find first a layer of clay, representing a time of deposit of sediment; then of animal remains, such as marl or infusorial earth (including the tests of diatoms), and above this a bed of peat. Hundreds of sections similar to this have been revealed in various parts of New York, the best with which I am acquainted being those at the cement works at Cassadaga Lake, in Chautauqua County. Here the lakes are not entirely filled, but during the process of filling have been divided into several lakes and swamps, so that every stage in the lake destruction may be seen. Marl is often formed by the intervention of fresh water algæ.

Such conditions as these are best found where the sediment supply is slight. In some places there is so little clay and sand furnished that the organic deposits are most prominent. For instance, some of the ponds occupying kettles in the moraine near Cortland have such a slight drainage area that they receive so little sediment that their beds are made exclusively of a marl (Fig. 109).

Elsewhere the lake filling is mainly accomplished by vegetation from first to last, because almost no sediment is supplied. This is illustrated in the case of ponds and swamps in the wooded region of the Adirondacks and in the tiny kettle-ponds in parts of the moraine; but on a larger scale it is illustrated in the lakes and swamps of southern Florida, where the streams bring almost no sediment, and the lakes are being changed to swamps by an accumulation of vegetable muck which in places is several feet thick. Such deposits as these may be considered as embryonic coal beds.

Thus sediment filling, aided by plant and animal deposit, is engaged in the extermination of lakes, and the first result is the formation of swampy land. In this State there are instances of every stage of lake-filling from the beginning to the end. Later the swamps will be drained by natural processes, for the streams are then able to flow across the deposits (Fig. 119), and thus help to drain and to excavate them, so that finally the swampy tracts are transformed to dry plains drained by the very streams that helped to form them. In time all the lake deposits will be removed from a valley, and this completes the life history of the lake. Of this process of removal of lake deposits there are instances in this State, though in most cases the time since the glacial period, when the lakes were formed, has been so brief that filling is generally incomplete.

Not all lakes pass through this normal cycle of development; some are subjected to accident by which they are removed. For instance, a lake held behind an ice dam will disappear when, by melting, the dam is removed. This has been the history of the ice-dammed lakes of New York. With so insecure a dam such lakes are very uncertain, as one may plainly see along the ice margin of Greenland, where in a single season such lakes form and disappear.

Another cause for disappearance of lakes by other than the normal processes is a change in the climate from moist to dry. If, for example, the climate of the Great Lakes should change to one of aridity, they would gradually shrink until they were disconnected, and this shrinking might continue either until the basins became dry areas of interior drainage, or were occupied by shallow lakes, saline in character through the concentration of the salts furnished by the water, but no longer removed by overflow and incapable of being removed by evaporation.

Such a condition as this exists in many arid lands, notably in Central Asia and our western Great Basin, in which one of the basins holds the Great Salt Lake. While this condition is now absent from New York, the presence of extensive beds of Silurian salt suggests the possibility that, at that early period, the supposed conditions of aridity actually did exist within the confines of the State; and in the changes of climate which have occurred since then, of which we feel certain that there have been many, though we cannot specify each of them and point out its effects, there may well have been similar changes in later periods; indeed, others still may be in store.

SWAMPS.—There are various ways in which swamps may be formed, but perhaps the commonest swamp in New York

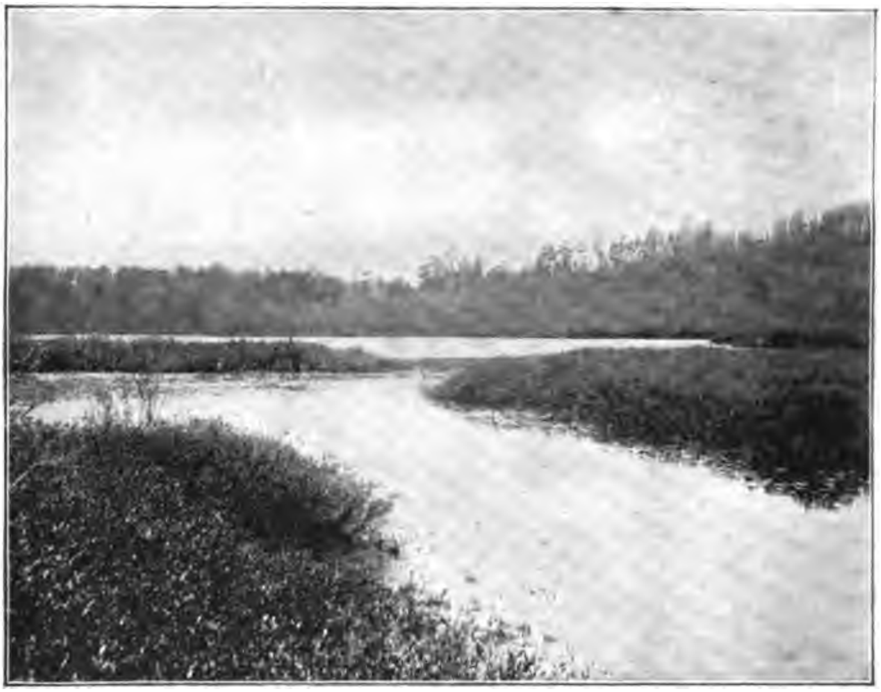

FIG. 116. Swampy shore of Clay Pond, Bourne, Massachusetts (Fig. 118) (J. L. Gardner, 2d, photographer).

is that caused where underground water escapes to the surface on a hillside, or at the base of a hill, and finds its run-off retarded, either by the growth of vegetation or by the levelness of the ground. With the removal of the forests many swamps of this kind have disappeared, and their sites are marked by the presence of a dark carbonaceous soil. In other cases the supply of water is so great that the mere removal of trees is not sufficient to drain the surface, and then, in some instances, artificial drainage has been resorted to.

Swamps of this kind, although abundant, are small. They are found in great numbers in the morainic country, where the water readily percolates through the stratified drift, but is retarded, and even forced to escape to the air, when it reaches the more compact underlying boulder clay. Sometimes a linear swamp is then formed along a part of the base of a hill, or sometimes the water seeps out of the soil on a hillside, where, by a little excavation, a spring can be made. The swamp-loving vegetation, the sphagnum, etc., grows abundantly here, and spreads, finally causing a small hillside swamp. In the damp climate of Scotland and Ireland the sphagnum bogs at times become so saturated with water that they commence to flow down the hillside, often causing considerable destruction.[1]

Long linear swamps are also formed in many places along the base of the beaches that were built when the waters of the Great Lakes stood at a higher level. The rain soaks down into the gravel, but is not so easily able to enter the underlying clays. Such swamps as these abound along the north faces of the beaches formed during the high stages of Lake Erie in Chautauqua County.

Swamps, often of a temporary nature, are formed on the floodplains of the New York rivers, but they are commonly dried up shortly after the river floods have subsided. Such swamps may be seen along the Upper Mohawk, where that

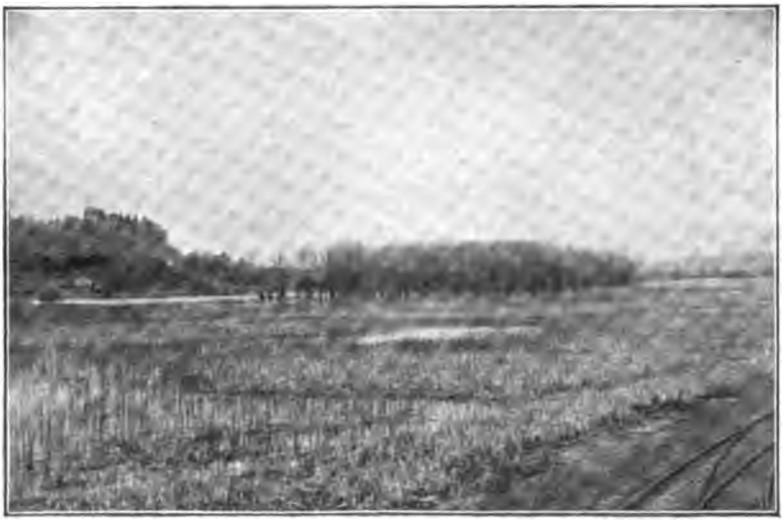

FIG. 117. Swampy portion of Inlet Delta, head of Cayuga Lake (C. S. Downes, photographer).

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[1] See Früh, Viertel, Naturfors, Gesells, Zürich, XLII, 1897, 202-237.

river is flowing over the level plain of the old lake bottom. These swamps, on a small scale, are the counterpart of the great swamps of large floodplains, like those of the Mississippi, the Yellow, etc.

Of the *large* fresh-water swamps, which are very abundant, the great majority are connected with some part of a lake history. For instance, a bay, either on sea or lake shore, becomes shut in by bars, and, upon being filled, is changed to a swamp. Or, even without an enclosing bar, a bay along a lake shore may become a fresh-water swamp by mere filling as the result of sediment brought by tributary streams. The filling of any lake or pond will in time produce a swampy tract (Figs. 113–119). This process of lake-filling, together with the production of delta, lake shore and filled-lake swamps, has already been sufficiently described (pp. 207–213).

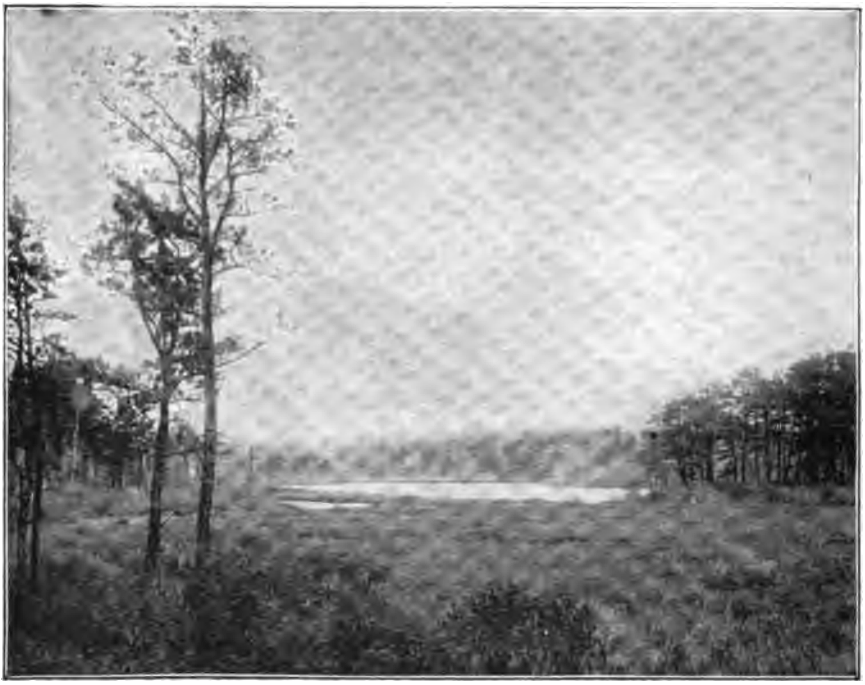

FIG. 118. Swamp replacing pond, Clay pond, Bourne, Massachusetts (Fig. 116) (J. L. Gardner, 2d, photographer).

Another class of lake swamps is that formed in connection with the disappearance of the ice. During the stand of the glacier the temporary lakes received deposits which were spread out with such levelness that swamps now exist on parts of the sites of many of them. Connewango swamp, in Chautauqua County, is situated in the bottom of an extinct lake, formed while the glacier was standing in that region.

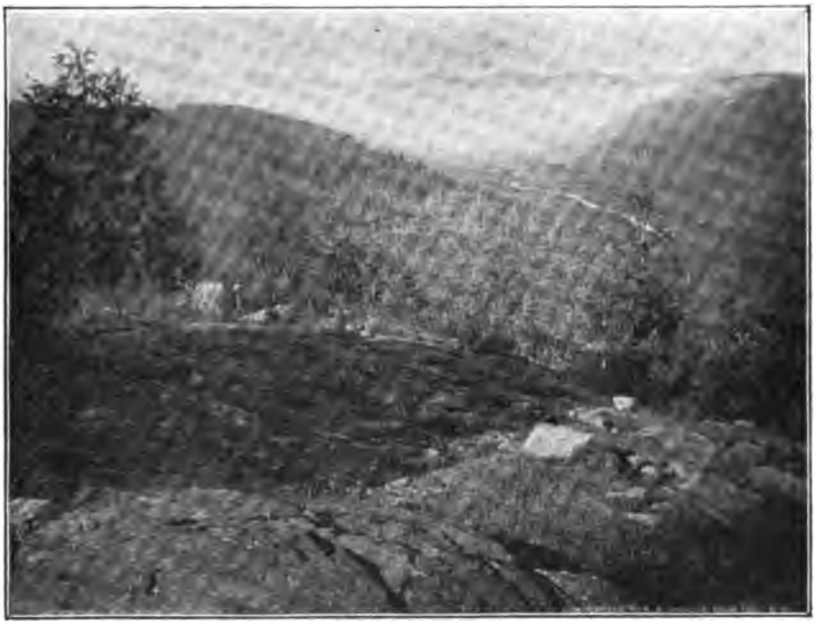

FIG. 119. Valley of the Boreas, illustrating swamp formed by lake filling (Copyright, 1888, by S. R. Stoddard, Glens Falls, New York).

Although the lake has now disappeared, its presence is marked by shore lines on the neighboring hillsides.

The Montezuma marshes, at the outlet of Lake Cayuga, also appear to be associated in origin with the withdrawal of the ice-sheet. One expects to find swamps at the *head* of lakes, where filling is in operation; but the *outlet* should not normally be the seat of an extensive swamp, as is the case with Lake Cayuga. It is known that the ice stood in this region for awhile, building moraines and evidently pouring sediment into the lake from streams which issued from its front. The sediment, entering a body of quiet water, naturally spread itself out in the form of a moderately level sheet. This shallowed the northern end of Lake Cayuga, so that in postglacial times it has become transformed to an extensive swamp, chiefly through the agency of vegetation, which has added the top layer. This swamp is even now encroaching southward upon the lake, which is shallow near the outlet end, where the clear lake water merges imperceptibly into the reed-covered swampy tract.

Gilbert[1] has brought forward evidence that the land in the Great Lakes region is still rising, tilting the land by raising it more in the north than in the south, and geological evidence points to the conclusion that it has been rising in the recent past. This tilting of the land has necessarily diminished the slope of north-flowing streams, and should tend to increase the swampiness of the lake deltas on the southern end of the Finger Lakes. Concerning such tilting Shaler[2] has suggested that the swampiness of one of the New England valleys, the Nashua, has resulted from this tilting, and it is not improbable that some swamps in New York are of the same origin. The swampy tracts along portions of the Champlain shore may also be due to the change in level of the land.

By far the most extensive swamps are those produced by the elevation of level sea-bottoms. Drainage upon them is at first so poorly developed that they are swampy, as is the case of the elevated sea-bottom of southern Florida and eastern Texas. Later, as the streams sink their channels into these level tracts, they become drained, as has been the case with the pine land plains of New Jersey (Fig. 33).

There are now no such sea-bottom swamp plains in New York, though during the elevation of the Appalachians their western face, even in New York, was skirted by plains which at first were undoubtedly swampy, similar to those upon which the coal fields of Pennsylvania developed. These have now been transformed by elevation and dissection to the central New York plateau, from which many of the overlying layers have been stripped, so that it is not impossible that the evidence of this swampiness, in the form of coal-beds, which may once have existed, has been removed in the course of denudation.

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[1] Nat. Geog. Mag., VIII, 1897, 233–247; Eighteenth Annual Report U. S. Geol. Survey, 1898, 595–647.

[2] Amer. Journ. Sci., XXXIII, 1887, 210–221.

CHAPTER VII

ORIGIN OF THE BASINS OF THE GREAT LAKES

DESCRIPTION OF THE ST. LAWRENCE SYSTEM.[1]—The St. Lawrence is quite unique among the river systems of the world. At its mouth the river and its tributaries are drowned, so that the salt water of the ocean enters to form the broad Bay of St. Lawrence, with its irregular margin. Even further out than this, there is indication of a river valley carved in the continental shelf and completely covered by the ocean waters. From the Bay of St. Lawrence up stream the water area narrows and the water freshens, though the tide rises nearly as far as Montreal, at which place the St. Lawrence is a very broad river, with gentle current. Just above this place, the river changes in habit, becoming a series of violent rapids, and from this point up stream there are frequent stretches of quiet water, separated by rapids. Then, at the outlet of Lake Ontario, the river passes through a maze of islands, beyond which is Lake Ontario itself, one of the five Great Lakes, which, because of their immense size and close connection, constitute one of the remarkable features of the system.

These several lakes are connected by broad rivers and straits, which, in places navigable, are elsewhere interrupted by rapids, and in one case by the greatest fall in the world, Niagara. The water area above the Thousand Island outlet of Lake Ontario, including the lakes and connecting streams, is about 95,275 square miles;[2] but to this entire area there is no large river tributary. As will be seen by the map (Fig. 120), the divide of the system sometimes runs close to the lakes, and is never very far from them. The total area of the Great Lake system is about 270,000 square miles, of which, as has been said, about 95,275 square miles is water. This of itself is a remarkable feature, and will be referred to later as having an important bearing on the history of the St. Lawrence system.

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[1] Schermerhorn, Amer. Journ. Sci., CXXXIII, 1887, 278–284; Vedel, Amer. Geol., XVIII, 1896, 196; Bigsby, Phil. Mag., 2d Ser., V, 1829, 1–15; 81–87; 263–274; 339–347; 424–431; Henry, Trans. Albany Inst., I, 1830, 87–112.

[2] Most of the figures and facts in this chapter are taken from Schermerhorn's valuable paper, Amer. Journ. Sci., CXXXIII, 1887, 278–284.

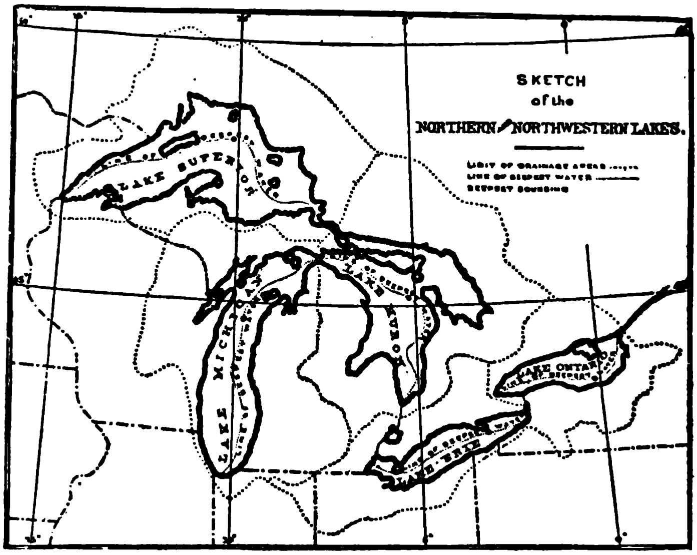

FIG. 120. Schermerhorn's sketch map of the Great Lakes.

" The water surface of Lake Superior nearly equals the combined areas of New Hampshire, Vermont, Massachusetts and Connecticut"; and the "combined area of the lakes exceeds the area of England, Wales and Scotland"; while "the length of shore line of the lakes and their connecting rivers is about 5,400 miles, or about equal to the coast line from Maine to the isthmus of Panama," ignoring minor indentations.[1]

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[1] Schermerhorn, Amer. Journ. Sci., CXXXIII, 1887, 279.

	Length, miles.	Average width, miles.	Maximum width miles.	Shore line, miles.	Water area (including islands, square miles.	Average depth, feet.	Maximum depth sounded, feet.	Surface above tidewater, feet.	Deepest point above tidewater, feet.	Water volume, cubic miles.	Land area of water shed, square miles.	Aggregate water and land area of water shed, square miles.
Lake Superior....	390	70	160	1,300	31,200	475	1,008	602	−406	2,800	51,600	82,800
St. Mary's River..	53 40	2½ 2	5 4	100	200	...	53	...	...	...	800	1,000
Lake Michigan ...	335	58	85	875	20,200	335	870	581	−289	1,290	37,700	60,100
Green Bay........	115	15	21	260	1,700	95	144	581	+437	30		
Mackinac Strait ..	30	16	23	60	500	75	234	581	+347	7		
North Channel....	110	12	18	220	1,400	70	240	581	+341	20	31,700	55,700
Lake Huron	250	54	100	725	17,400	210	702	581	−121	650		
Georgian Bay.....	120	40	58	390	5,200	170	462	581	+119	170		
St. Clair River....	35	1	...	70	30	...	...	...	...	...	3,800	3,830
Lake St. Clair	19	25	29	90	410	...	21	575	+554	1	3,400	3,810
Detroit River.....	27	2	3½	54	60	...	...	...	...	...	1,200	1,260
Lake Erie	25	40	58	590	10,000	70	204	573	+369	130	22,700	32,70
Niagara River	34	1	2	70	60	...	...	...	...	...	300	36
Lake Ontario.....	180	40	58	600	7,300	300	738	247	−491	410	21,600	28,900
St. Lawrence River	760	20	95	...	...	...	...	...	...	...	...	...
Totals	.....	.....	.....	5,404	95,660	.....	......	.....	......	5,508	174,800	270,460

Table copied from American Geologist (by Vedel), XVIII, 1896, 196.

From the table it is seen that Lake Superior is 602 feet above sea level, Huron and Michigan 581 feet, the descent between them being chiefly in the rapids of St. Mary's River. There is then a descent of about 8 feet to the level of Erie (573), mostly in Detroit River, while Ontario has an elevation of only 247 feet. Of this descent, 160 feet occurs *at* the Falls, 110 feet in the rapids of the gorge, and 50 feet in the rapids just above the Falls. This leaves only 6 feet of fall for the upper Niagara River above the rapids.

The beds of all the lakes, excepting Erie, are below sea level, and such a large area is below this level that even if their water surface were lowered down to the level of the sea, there would still remain large bodies of water in the sites of Ontario, Michigan and Superior, while Erie would disappear and Huron shrink to small size.

The rainfall of the entire lake area averages about 31 inches, being higher in the eastern than the northwestern end. This rainfall fills the lakes, satisfies percolation and evaporation, and furnishes for discharge 86,000 cubic feet per second from Lake Superior, 225,000 cubic feet from Michigan and Huron, 265,000 cubic feet from Erie through the Niagara, and 300,000 cubic feet per second from Lake Ontario. This aggregate discharge is double that of the Ohio, nearly half that of the Mississippi, and represents about one-half the rainfall, while in the case of the Ohio and Mississippi the discharge is equal to only about one-quarter of the rainfall. The total bulk of water in the river system is about 6,000 cubic miles, nearly one-half of which is in Lake Superior. This amount "would sustain Niagara Falls in its present condition for about 100 years.[1]

Portions of Lakes Erie and Ontario, the Niagara River and the upper St. Lawrence, lie within the State of New York; but while it is this portion alone which properly concerns us, no adequate discussion of the New York section of the system can be presented without including the entire drainage area. Naturally, the question of the origin and history of this interesting river system has attracted wide attention and has been the subject of much investigation and theorization. As the result, there have been gathered a large number of facts of various kinds, and there have been proposed numerous hypotheses.

It is no small task to weigh these facts and candidly discuss the various hypotheses; but since this has never been done, it seems well to attempt it. Within the limits of one or two chapters, it is not possible to do this with completeness, although the attempt is made to so discuss the subject as to consider the salient points. It must be admitted in advance that, in the main, a definite result will not be attained from this discussion: it is too early for final conclusions. But some facts and conclusions will be found to be established, while others may be considered probable. Never having written upon this general subject before, though for several years having had the question in mind, I feel able to approach it without bias, though in discarding as untenable some of the hypotheses that have been proposed, and in arguing against others, I realize that their advocates may not stand ready to accept my conclusions. All I claim for this discussion is that it is based upon a certain familiarity with the region, a careful and extended reading of the more important papers, and a candid consideration of the facts obtained from these two sources.

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[1] Schermerhorn. Amer. Journ. Sci., CXXXIII, 1887, 282.

PREGLACIAL HISTORY.—It is evident that before the glacial period, the country included in the St. Lawrence river system, together with other parts of northeastern North America, had for a long time been subjected to denudation. No modern geologist questions this, and the evidence of it may be found on every hand. The result of this exposure to denudation was the transformation of the land into a series of hills and valleys, occupied and drained by rivers. Our *general* land topography has been produced by this long denudation, and no one questions that at least a part of the form and topography of the valleys of the Great Lakes has resulted from its action.[1]

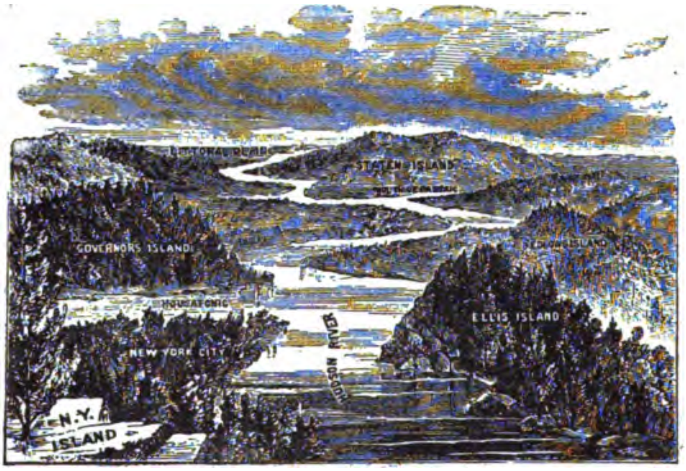

FIG. 121. Newberry's ideal restoration of the New York region in preglacial times.

Another fact upon which there is probably no difference of opinion, is that, in the period before the general glaciation, the land stood at a higher level than now and that it stood at such a level for a long time. The exact amount of this elevation is unknown; but off the coast of eastern America the depression since that time has been enough to completely submerge the lower ends of some river valleys, while in the region of the present lower St. Lawrence it was sufficient to drown the main valley and its tributaries, such as the Saguenay. The elevation certainly amounted to many hundreds of feet, and it lasted long enough for rivers to carve deep and broad valleys of mature form, portions of which are now completely obscured from view by a submergence below the ocean water.

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[1] Agassiz (Proc. Amer. Assoc. Adv. Sci., I., 1849, 79; Lake Superior, Boston, 1850, 417–426) points out that the detailed outline of part of the shore of Lake Superior is due to the presence of dikes, indicating that denudation has been influenced by them.

Whether the Great Lakes existed before the glacial period, cannot be stated positively upon direct evidence, though without doubt most physiographic geologists will agree that they did not. The reasons for this conclusion are, in the first place, that we know of no cause for their existence immediately before the glacial period. Lakes, even the great ones, are not long-lived, as geological time goes, and had they been formed during a period much earlier than the present, they would have long since been destroyed by filling. In the second place, and more important than the other point, it may be said that, had they existed, there should have been formed extensive lake deposits, containing lake fossils, some evidence of which should have been discovered in the course of the careful study of the lake shores and the drift-covered country south of them.. This negative evidence, and the fact that lake basins must have a definite cause, has weight of sufficient importance to lead to the conclusion that the Great Lakes probably did not exist in preglacial time.

By what, then, were the present valleys occupied? In considering this subject, we leave for later discussion the question of the origin of the present *closed* basins, and assume the existence of valleys, without raising the question whether they were then as deep as now. Were these valleys occupied by the preglacial St. Lawrence River? This question may be answered positively by the statement that no such river existed along the present line of passage of the St. Lawrence water. Whatever the preglacial drainage may have been, no river that was able to form an upper valley like that of Superior, Huron and Michigan would then change to a Detroit river, or to a Niagara. All would agree that the present course is not *exactly* the preglacial course.

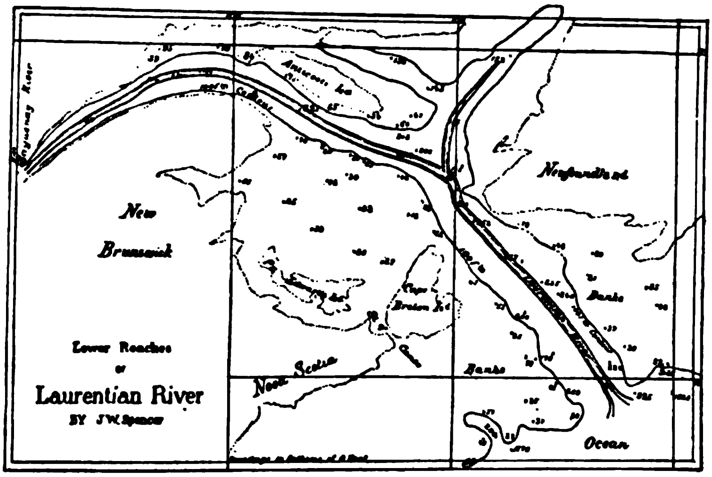

FIG. 122. Spencer's interpretation of the preglacial course of the lower St. Lawrence.

However, when we come to consider how far this preglacial course differed from the present one, we come to a point where diversity of opinion exists. Numerous attempts to reconstruct parts or the whole of the preglacial drainage have been made, and some investigators have pointed out the existence of buried channels, revealed by borings, and have shown that they may represent the preglacial courses of some parts of the St. Lawrence system.

For instance, Newberry[1] notes the existence of buried river valleys, notably the Cuyahoga, which enters the valley of Lake Erie at a depth considerably below the lake surface. This he takes as evidence that the Lake Erie valley was a preglacial valley at a time when the land stood higher, namely at the time when the drowned valleys of the coast were formed.

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[1] Proc. Boston Soc. Nat. Hist., IX, 1862–63, 42–46. See also later articles by Newberry (referred to on p. 232). Also Winchell, Amer. Journ. Sci. CII, 1871, 15–19; Orton, Geol. Survey Ohio, Vol. I, 1873, 425–434; 438–449; 455–462; Geol. Survey Ohio, Vol. VI, 1888, 772–782; Spencer, Proc. Amer. Phil. Soc. XIX, 1880–81, 300–337; and later articles, (see p. 245); Foshay, Amer. Journ. Sci. XL, 1890, 397–403; Leverett, Amer. Journ. Sci. XLII, 1891, 200–212; Hershey, Amer. Geol. XII, 1893, 314–323; Mudge, Amer. Geol., XII, 1893, 284–288; same, XIV, 1894, 301–308; same, Amer. Journ. Sci. L, 1895, 442–445; same, Amer. Journ. Sci. IV, 1897, 383–386; Chamberlin and Leverett, Amer. Journ. Sci. XLVII, 1894, 247–283; Upham, Bull. Geol. Soc. Amer., VII, 1896, 327–348; same, VIII, 1897, 6–13; Pierce, Amer. Geol., XX, 1897, 176–181.

His view is carried a step further in later articles,[1] where he points out the existence of a buried channel at Detroit 130 feet below the city, and another south of Lake Michigan 230 feet deep. He also shows that Onondaga Lake of New York has beneath it a depth of 414 feet of drift deposit, so that the rock surface there is 50 feet below sea level.[2] The great depth of drift near Syracuse, together with other facts, led Newberry to the conclusion that the preglacial drainage of at least the eastern lakes found outlet through the Mohawk and the Hudson.[3] This interpretation is opposed by Carll,[4] and by Lesley,[5] the latter calling attention to the fact that, according to this view, there must be a channel near Little Falls, New York, with at least 1,000 feet of drift-filling. It is doubtful if any one who is familiar with the Mohawk valley would now hold this view of Newberry's, for there seems to be no opportunity for such a river at this place. At Little Falls the valley is crossed by rock, and on either side of the river there is no place for the existence of a valley of such a depth and of sufficient width to correspond to the depth. Moreover, Brigham (p. 182) has recently proved very clearly that the region about Little Falls represents a divide, and that the Mohawk is a complex of two streams, one east-flowing, the other west-flowing.

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[1] Newberry, Geol. Survey Ohio, 1869, 24–31; Annals New York Lyceum Nat. Hist., IX, 1870, 213–234; Amer. Nat., IV, 1870, 193–214.

[2] Newberry first said that the Cuyahoga channel was 100 feet below the lake surface; but later (Geol. Survey Ohio, I, 1873, 175) he shows that the depth is as much as 228 feet. Upham (Bull. Geol. Soc. Amer., VIII, 1897, 6–13), finds the depth of the channel to be 470 feet below lake level.

[3] Pop. Sci. Mon., XIII, 1878, 641–660; Proc. Amer. Phil. Soc., XX, 1882–83, 91–95.

[4] Second Geol. Survey Pennsylvania, Report III, 1880, 369.

[5] Proc. Amer. Phil. Soc., XX, 1882–83, 95–101.

Spencer has also[1] attempted to reconstruct the preglacial drainage of the Great Lakes and has pointed out the existence of numerous buried valleys, notably one apparently connecting Lakes Erie and Ontario, via Hamilton, in Ontario. He has realized the difficulty of proposing an outlet for Ontario, because neither the Mohawk nor the St. Lawrence courses seem adequate, and there is no other place apparent. This difficulty he meets by assuming that the outlet has been closed by the tilting of the land, so that the old valley, which was approximately along the line of the present St. Lawrence, no longer slopes eastward. As will be seen by the map (Fig. 123), Spencer locates the sites of these supposed rivers, and gives them names.

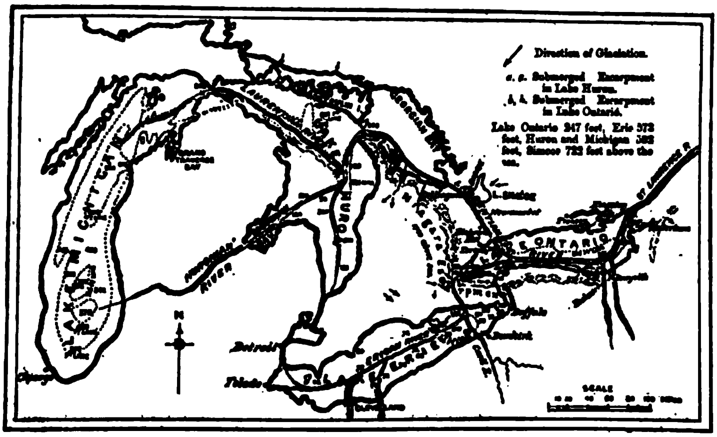
Direction of Glaciation.
a. a. Submerged Escarpment in Lake Huron.
b. b. Submerged Escarpment in Lake Ontario.
Lake Ontario 247 feet, Erie 573 feet, Huron and Michigan 582 feet, Simcoe 722 feet above the sea.
L. Simcoe
ONTARIO
ST LAWRENCE R.
HURON
Detroit
Toledo
N
SCALE

FIG. 123. Spencer's interpretation of the preglacial course of the drainage of the Great Lakes region.

Still another opinion concerning the former course of the drainage of the Great Lake region is that much of the water formerly outflowed to the Gulf of Mexico through the Mississippi River.[1] Our knowledge of the Canadian region is too limited to permit the assumption that none of the drainage found its way northward in preglacial times.

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[1] Proc. Amer. Phil. Soc., XIX, 1880–81, 300–337; Second Geol. Survey Pennsylvania Rept. QQQQ, 1881, 357–406; Proc. Amer. Assoc. Adv. Sci., XXX, 1881, 131–146; same, XXXVII, 1888, 197–199; Bull. Geol. Soc. Amer., I, 1889, 65–70; Quart. Journ. Geol. Soc., XLVI, 1890, 523–533; Amer. Geol., VII, 1891, 86–97; Pop. Sci. Mon., XLIX, 1896, 157–172; Amer. Geol., XXI, 1898, 110–123. A number of Spencer's papers are republished in the appendix of the 11th Annual Rept. of the Niagara Reservation Commission, 1895. Some of Spencer's other papers (p. 245), refer to this view of the preglacial drainage.

Thus it is seen that, while we know that there were valleys in preglacial times, there is no consensus of opinion as to their course. On the part of some it has been a common assumption that the buried valleys discovered in borings are all preglacial; but by others it has been suggested that some of them are interglacial. For instance,

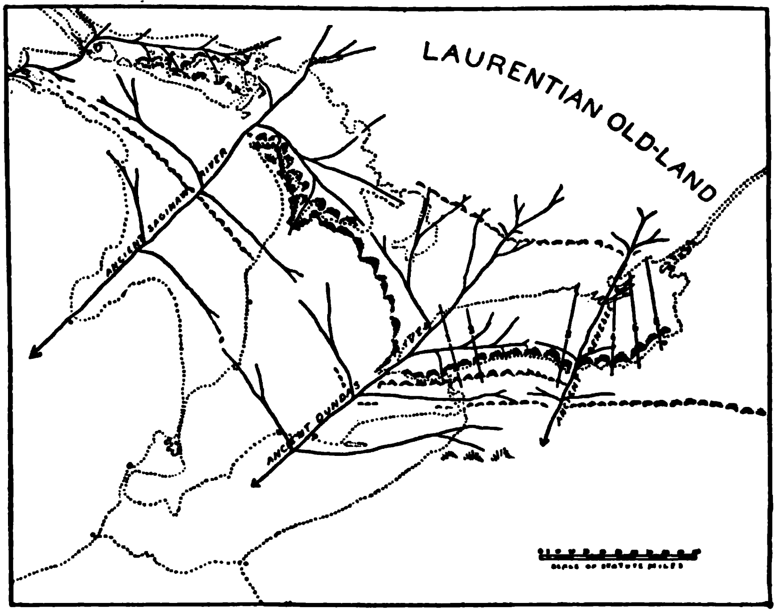

FIG. 124. Grabau's interpretation of the original consequent drainage of western New York. (New York State Museum, Bulletin No. 45, 1901).

Newberry[2] says that the preglacial valleys having been enlarged, were later connected by canyons, and again occupied by ice, and finally by drift. Upham[3] explains the narrow and deep canyon-like buried valleys as a result of the uplift which preceded the glacial period.

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[1] See, for instance, Russell, Lakes of North America, Boston, 1895, 97; Upham, Amer. Geol., XVIII, 1896, 169–177; Bull. Geol. Soc. Amer., VIII, 1897, 6–13.

[2] Proc. Amer. Phil. Soc., XX, 1882–83, 91–95. See also Hershey, Amer. Geol., XII, 1893, 314–323.

[3] Bull. Geol. Soc. Amer., VIII, 1897, 6–13.

From this maze of conflicting opinions it is difficult to determine upon the correct explanation. One point seems fairly clear—that the *preglacial* valleys were not as deep as the present ones. The lake basins are broad, boat-shaped valleys; but there are no equivalent valleys connecting them. Instead, deep canyons are found in a few places, and these are assumed to represent the connecting rivers. Those who advocate this view fail to explain why a broad valley abruptly narrows to a canyon, when there is no noticeable variation in rock structure.

Since there are no broad, connecting valleys, it follows that the present depth of the basins has been caused by some change in conditions, and this conclusion will be discussed further on. How much these basins have been deepened is not now apparent; but among all the facts that we have, there are none which would disprove the view that the original old valley bottoms might have been as high as the level of the present lake surface. With so much uncertainty, it is evident that it is difficult to trace the preglacial course of the rivers involved in the carving of the valleys.

The buried gorges connecting the basins may be due to immediately preglacial uplift, as suggested by Upham,[1] or they may be interglacial gorges. They are certainly younger in form, and hence in age, than the preglacial valleys with which they are associated; and while they *may* mark the approximate course of the preglacial rivers, they may, on the other hand, represent a course far divergent from the original preglacial course. So it seems that any argument in favor of preglacial courses which is based upon evidence obtained from the drift-filled canyons is not necessarily valid.

My own belief is, that the present Great Lakes system is a complex made by the union of portions of several streams as the result of various accidents, particularly the glacial accidents. There may be portions of the St. Lawrence, of the Mississippi, and possibly even of the Arctic drainage, united by these accidents to form the present complex.

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[1] Bull. Geol. Soc. Amer., VIII, 1897, 6–13.

One of the reasons for proposing this view is that there appears to be no continuous development of the system in any one direction. A well developed river valley naturally

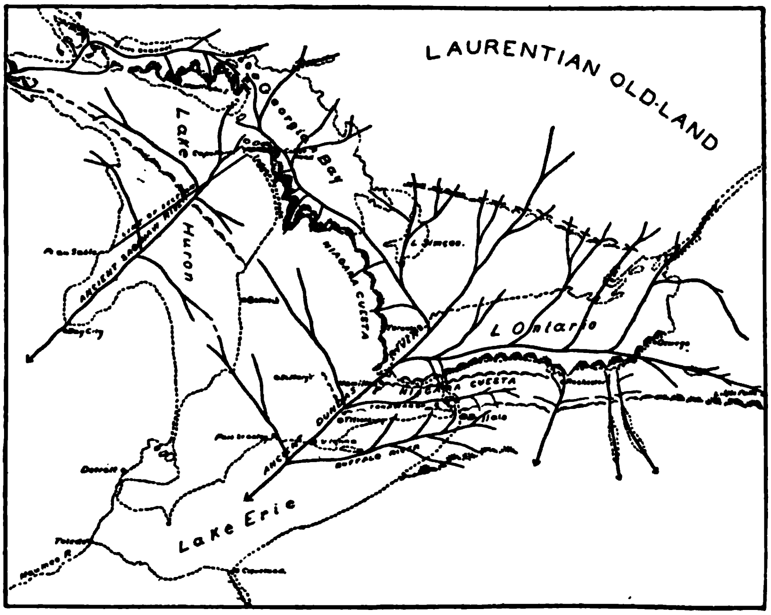

Fig. 125. Grabau's interpretation of preglacial drainage of northern New York—a later stage of development than Fig. 124 (New York State Museum, Bulletin No. 45, 1901).

broadens from its head to its mouth. The Great Lakes system does not do so, either toward the Mohawk, St. Lawrence or Mississippi. The St. Lawrence River itself, it is true, does broaden eastward; but this is not connected with a similar change in that part of the system which is occupied by the Great Lakes.

Another argument against the belief that this region represents a single preglacial system is the fact that the drainage area is so small. In a number of places the divide is so close to the lake shore that we can see the lake from the divide (Fig. 120), and nowhere are they far removed from one another. It is true that the system has been robbed of some of its preglacial drainage;[1] but even restoring this liberally, there still remains a drainage area so small, with tributaries of large size so notably few, that the condition seems an impossible one for a large river system. Moreover, in a river system hundreds of miles in length, there should naturally be an increase in the number and size of large tributaries as one passed down stream; but no such increase is noticed in the St. Lawrence system. In other words, the different portions do not have the appearance of a part of a *single* large system.

Origin of the Lake Basins.—Whatever view has been prominently held concerning the preglacial history of this region, it has been uniformly agreed that during or immediately after the glacial period, the preglacial valleys have been transformed to basins. It has been shown that the zone of abundant lakes in northern Europe and America lies within the glaciated belt. While we now know that most of these lakes are the result of irregular drift deposits, Ramsay advocated the view that many were due to ice erosion,[2] and suggested that the Great Lakes themselves were rock basins carved out by ice erosion.

It is to Newberry,[3] however, that we owe a fuller development of this idea of ice erosion as applied to the Great Lakes basins. He recognizes Lake Superior as a synclinal trough, but believes that the other basins have been cut by some mechanical agent out of formerly continuous and nearly horizontal sheets of sedimentary strata. This mechanical agent he believes must be either ice, or water, or both. He notes that all have been filled by ice, and says,[1] "No other agent than glacial ice, as it seems to me, is capable of excavating broad, deep, boat-shaped basins like those which hold our lakes." The ice movement is favorable to this explanation.[2] Others have followed Newberry in ascribing the lake basins to ice erosion in part at least.[3]

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[1] See pp. 158–161, 170 and 182; also Carll, Second Geol. Survey Pennsylvania Rept. III, 1880, 330–397; same, Rept. IIII, 1883, 169–175; Foshay, Amer. Journ. Sci., XL, 1890, 397–403; Chamberlin and Leverett, Amer. Journ. Sci., XLVII, 1894, 247–283; Brigham, Bull. Geol. Soc. Amer., IX, 1888, 183–210.

[2] Quart. Journ. Geol. Soc., XVIII, 1862, 185–204; Amer. Journ. Sci., XXXV, 1863, 324–345: Physical Geology and Geography of Great Britain, 1872, 176.

[3] Proc. Boston Soc. Nat. Hist., IX, 1862–63, 42–46; Geol. Survey Ohio, 1869, 24–31; Annals New York Lyceum Nat. Hist., IX, 1870, 213–234; Amer. Nat., IV, 1870, 193–214; Geol. Survey Ohio, I, 1873, 47–49; 174–184; same, II, 1874, 21–65; 72–80; Proc. New York Lyceum Nat. Hist., II, 1874, 136–138; Geol. Survey Ohio, III, 1878, 32–51; Proc. Amer. Phil. Soc., XX, 1882–83, 91–95.

Carll[4] believes that there were at first preglacial valleys which were somewhat enlarged by the glaciers, but mostly increased in size by subglacial waters. From his statement, it is not perfectly clear just how he accounts for all the facts by this action, and it is doubtful whether he would hold this view at the present time.

In his discussion of the Red River Valley, General Warren[5] brings forward evidence of tilting of the land; and Spencer,[6] who has vigorously opposed ice erosion, even to the extent of denying its potency as a partial agency, applies this change of level, which Gilbert had previously proved to have occurred in the Great Lakes region, to the explanation of the basins of the lakes. In his various papers Spencer argues that the tilting of the land has actually closed some of the valleys, notably that of Ontario, transforming them to basins, so that the failure to find a broad, deep, drift-filled outlet is not proof of ice erosion. According to Spencer, the differential elevation, which was greatest in the north and northeast, formed three lakes—Superior-Huron-Michigan, Erie, and Ontario. Spencer affirms that the glacial striæ are not parallel to the lake basins and hence that the ice erosion theory is not tenable.

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[1] Annals New York Lyceum Nat. Hist., IX, 1870, 232.

[2] See Newberry, Proc. Amer. Phil. Soc., XX, 1882–83, 91–95. See also Chamberlin's map of glacial striae, 7th Annual Rept. U. S. Geol. Survey, 1888, facing p. 155.

[3] See, for instance, Logan, Geol. Survey of Canada, 1863, 889; Winchell (for Green Bay) Amer. Journ. Sci., CII, 1871, 15–19; Russell, Pop. Sci. Mon., IX, 1876, 539–546; Gilbert, Forum, V, 1888, 417–428; Tarr Bull. Geol. Soc. Amer., V, 1894, 339–356 (see criticism of this by Spencer, Amer. Geol., XIV, 1894, 134–135, and reply by Tarr, same, 194–195.)

[4] Second Geol. Survey Pennsylvania, Rept. III, 1880, 367–376.

[5] Annual Rept. Chief of Engineers, 1868, 307; Amer. Journ. Sci., XVI, 1878, 416–431.

[6] Proc. Amer. Phil. Soc., XIX, 1880–81, 300–317; Second Geol. Survey Pennsylvania, Rept. QQQQ, 1881, 357–406; Proc. Amer. Assoc. Adv. Sci., XXX, 1881, 131–46; Geol. Mag. IV, 1887, 167–173; Amer. Nat. XXI, 1887, 168–171; Proc. Amer. Assoc. Adv. Sci., XXXVII, 1888, 197–199; Bull, Geol. Soc. Amer., I, 1889, 65–70; Quart. Journ. Geol. Soc., XLVI, 1890, 523–533; Amer. Journ. Sci., XLI, 1891; 12–21; Amer. Geol., VII, 1891, 86–97; Proc. Amer. Assoc. Adv. Sci., XLIII, 1894, 237–243; Amer. Geol. XIV, 1894, 298–301; Pop. Sci. Mon., XLIX, 1896, 157–172; Amer. Geol., XXI, 1898, 110–123; 11th Rept. Niagara Comm., 1895, Appendix (reprint of several papers). For a more complete list of Spencer's papers, see p. 245.

While others besides Spencer have argued against the glacial erosion theory,[1] perhaps the strongest argument against it is that by Claypole,[2] who holds that glaciers are not powerful enough to perform the work, and that the drift supposed to have been excavated from the basins does not exist to the south of them. Davis[3] says that the evidence of glacial erosion is very meager, hardly more than proof that the valleys were occupied by ice (p. 341 in [3]). The rocks are nearly horizontal, and the lakes lie mostly in the softer strata. Davis inclines toward drift obstruction of river valleys as the chief cause for the basins (p. 362 in [3]). Upham[4] believes the chief cause of the basins to be warping of the crust before, during and after the ice age. No doubt most of these writers, while favoring one cause as the prime one, would agree to the hypothesis that several causes have co-operated, as is stated by Davis,[5] and by Russell,[6] who, though first advocating ice erosion, now believes them to be due to land movement and other causes.

Perhaps the broadest statement of origin of the Great Lakes is that by Chamberlin,[7] who ascribes the Great Lakes basins to the joint action of "preglacial erosion, glacial corrasion, glacial accumulation blocking up outlets, depression due to ice occupancy and general crust movements, together with possible unascertained agencies." This is certainly broad enough. Taylor[1] believes in four causes—stream action, tilting of the land, obstruction by drift and deepening by ice action. He believes the basins to be old river valleys which have been tilted and choked by glacial deposits, but thinks that the ice sheet had little or no tendency to deepen.

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[1] See, for instance, Lesley, Second Geol. Survey Pennsylvania, Rept. QQQQ, 1881, 399–401; Proc. Amer. Phil. Soc., XX, 1882–83, 95–101; Bonney, Nature, XLIII, 1891, 203–4.

[2] Proc. Amer. Assoc. Adv. Sci., XXX, 1882. 147–159.

[3] Proc. Boston Soc. Nat. Hist., XXI, 1883, 315–381. In a recent paper Prof. Davis has announced a fuller appreciation of the power of ice in eroding valleys.

[4] Amer. Geol., XVIII, 1896, 169–177.

[5] Proc. Boston Soc. Nat. Hist., XXI, 1883, 341, 362.

[6] Lakes of North America, 1895; Bull. Amer. Geog. Soc. XXX, 1898, 226–254.

[7] Proc. Amer. Assoc. Adv. Sci. XXXII, 1883, 212.

As in the preceding section, it is difficult to select from these opposing views one which correctly explains the phenomena. That the basins are not due solely, or even primarily, to drift obstruction seems evident. It is inconceivable that there are buried and completely obliterated broad preglacial valleys; and, while we may agree that there *are deeply drift-filled valleys* between the lakes, it seems certain, from all the evidence, that these are *narrow* valleys formed in quite a different way from the broad, boat-shaped basins. The failure to find outlet channels, as, for instance, for the Ontario basin, may possibly be due to incomplete study; but it has been commonly assumed to prove that this basin is rock-rimmed, and all the evidence that we have tends to confirm this view. There could hardly be a valley over 700 feet deep, and broad enough to form the continuation of the preglacial Ontario valley, which is so completely obscured by drift that not the least trace of it has been found on the surface.

I feel that we may safely say that the upper lake valleys are disconnected, excepting possibly by narrow canyons. The *possibility* of such connecting canyons, as deep as the lake basins themselves, cannot be denied; but the probabilities are very much against their existence. So we are to explain, if not a rock basin, at least a rock basin in all parts excepting where these undiscovered buried channels exist. In other words, we must account for the deep boat-shaped basins, the problem which Newberry attempted to solve.

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[1] Dryer's Studies in Indiana Geology, Terre Haute, 1897, 92–93

Excepting Superior, which is stated to be in a synclinal valley, these basins are not due to structural causes. They lie in a region of nearly horizontal strata, so uniform in structure that the alternate expansion and contraction of the basins seems impossible on the assumption of mere river erosion. It is, however, proposed as a theory that a broad river valley, the preglacial St. Lawrence, has been so warped as to form these basins. That there has been warping, and that this has had a marked influence on the form and depth of the lakes, must be admitted, as must also be the certainty that drift deposit in pre-existing valleys has tended to the same result. But to ascribe to such warping the predominant influence seems an extravagant use of the facts. It is a curious fact, if this explanation be true, that this particular region should have been selected for such warping, and have produced five great basins, when other valleys not far different, nor greatly removed from these, as, for instance, the Red River Valley of the North, where warping has also occurred, have not been transformed to basins. This, of course, is not an unanswerable argument against warping, but it may be pointed to as opposing evidence.

The warping has been complex, if it is the prime cause for the basins; and it has been considerable if it is the cause for the depth of 700 or 800 feet noticed in Lakes Ontario and Michigan; for, as has been pointed out before, we have to account for *deep*, *broad* valleys. Nearly the entire depth of each of these lakes must be accounted for by some other cause than river erosion, for it has been shown that the only possible valleys markedly below the lake levels are gorges, and hence that the only possible deep preglacial valleys along the sites of the present lakes, and markedly deeper than the present water surface, must have been gorges and not broad basins. So, in order to account for the basins by warping, we must assume warping to nearly the full extent of the present lake depth. Of such marked change in level there is no evidence either in the strata, or in the tilted beaches;

and it is doubtful if such warping has actually taken place.

In various parts of New York and the neighboring States gorges are found, which some writers have ascribed to interglacial river action, others to the immediately preglacial uplift which rejuvenated the region. It is a significant fact that, although these deep valleys have been discovered along the lake shore, and buried gorges appear to connect some of the Great Lakes, there is no sign of their existence on the lake bottom, as we might expect if the lake basins were due to warping. While this is not necessarily proof of their absence along the lake bed, it is suggestive.

So far as I am able to interpret the facts at present known, while Superior is perhaps located in a structural valley, and Erie very probably represents a broad, shallow valley, somewhat obscured by glacial deposit and transformed to a lake largely by tilting of land, and while both drift filling and tilting may be admitted as partial causes for the other lakes, I find it impossible to accept the warped-basin origin as the primary cause for the lakes. This leaves as the sole remaining explanation that of ice erosion. By this theory much, if not most, of the depth of the basins is ascribed to glacial erosion, operating to enlarge pre-existing valleys to boat-shaped basins.

It must be admitted that the process of elimination of other theories has probably not been complete enough to satisfy their supporters; and, perhaps, in this brief statement the argument has not been as clearly stated as it might have been. Enough has been said, however, to show that there are grave difficulties. Let us see if the ice erosion theory has equal objections. The argument *against* this theory has been very weak in the main. Contrary to opposing statements, the striæ *do* run in favorable directions, in the case of all the lakes excepting possibly Erie, which is least likely to be a rock basin of ice erosion origin. Professor Claypole's argument that there is not enough drift beyond the lakes to account for the basins through ice erosion would probably not now be repeated.

As for Ontario, the lake concerning which I would especially speak, there is drift enough between its southern border and the Pennsylvania moraine, and directly in line with it, to fill it many times. It must also be remembered that a vast amount of the ice load of rock fragments went down toward and even into the ocean.

Professor Davis' statement, that the evidence in favor of the ice erosion theory is hardly more than proof of occupancy of the basins, scarcely does justice to Newberry's argument. Newberry's point that we have here several separated, boat-shaped basins, although never fully elaborated by him, is a point which must be considered as strong evidence for the theory. Spencer's chief argument against the ice erosion explanation, namely that ice cannot do this work, is based upon a personal estimate of the erosive power of ice, which he gained partly from theory and partly from observation on the *margin* of small Norwegian glaciers. One can scarcely study the existing Greenland ice cap ard the American glacial deposits and still hold such a conception of the weakness of ice action. How Dr. Spencer reconciles his conception with the fact that the ice removed not only the residual soil and partly decayed rock over large areas, but also much of the fresh rock, is difficult to understand.

I have often wondered whether those who object to ice erosion because of the immense work required, are not sometimes confused by the exaggerated vertical, which is so often used in cross-section. I have heard people say that they did not believe glaciers were able to come down into a valley and dig a hole there. If one will draw a cross-section of the Ontario or the Lake Cayuga "hole," or will ascend to a hill overlooking such a lake as Cayuga, and see what a mere scratch the basin is compared with the valley itself, the difficulty of the ice erosion does not appear so great, as I well know from repeated experiments with students who have argued against the theory that Lake Cayuga is a rock basin.

In the long continued passage of the ice through a valley, a very little extra work done locally, where the rock is soft, or the ice deep, or its current more rapid than usual, would readily excavate a basin. Are there any reasons for believing that there might have been slightly more work done in the valley where Ontario now stands? The answer to this seems to be *yes*. In the first place, there is the difficulty of otherwise explaining it; and, in the second place, there is the fact that the Great Lakes are grouped in a place where the ice from the Labrador region found free passage out over the south-sloping plains, which at that time were probably more freely sloping.

Coming down into these broad, preglacial valleys, which have possibly been deepened by canyon cutting in their bottoms, as the result of the preglacial elevation, the glacier passed through them; and the very fact that they *were* valleys gave to the ice greater power to excavate, as one may see so well illustrated in the rapidly moving valley tongues from the Greenland ice cap. The rigidity of the ice would prevent this excavation from being uniform, and, as a result of this irregularity of work, rock basins would result. In the case of Ontario there is an added cause for deepening at the exact place where we find the basin. The Adirondack mountain mass obstructed the southward flow of the ice, deflecting some down the Champlain valley, but much more to the westward, so that the Ontario region was occupied by ice, coming not merely from the north, but also from the northeast. This must have meant more rapid movement and hence more rapid work at that place.

While I would not say that it is proved, I do hold that the ice erosion theory is the one to which the least serious objections have been offered. It seems a reasonable explanation for all the lakes, excepting Erie and possibly Superior, and has best stood the test of investigation; so well, in fact, that I feel warranted in putting it forth as the most probable of all the various theories, though with the distinct understanding that the effects of drift-filling and warping are recognized as added causes for the present area and depth of all the lakes.

CHAPTER VIII

POST-GLACIAL HISTORY OF THE GREAT LAKES

EARLY OBSERVATIONS.—Indian trails in New York were located upon a gravel ridge, which later became the site of a road, known as the ridge road. This gravel ridge was early recognized as a lake beach. For instance, Governor Clinton[1] said that a lake evidently once covered this region, its level having been lowered either by an earthquake shock or by the enlargement of the outlet. Atwater[2] stated that Lake Erie was once higher, covering the prairies of the Ohio region, and flowing into the Ohio, the level of this lake having been lowered by the cutting of the Niagara gorge. Bigsby[3] pointed out that elevated beaches prove that there have been fluctuations in the level of Lake Huron, and he also mentioned the elevated beaches near the shores of Lake Ontario,[4] as did Captain Basil Hall,[5] who recognized that Lake Ontario once stood higher.

Whittlesey[6] advocated beach origin for the ridges in Ohio, but pointed out the difficulty of explaining them, because of the absence of natural barriers. Later[7] he studied these beaches more extensively; and, after proving that they were not strictly level, concluded that they therefore were not beaches, but probably due to marine currents, being in the nature of bars. The same author later studied the beaches of the Michigan region,[8] and stated that the lower ones were lake beaches, exposed to the air by a lowering of the outlet, but that the upper ones were more ancient, and due to a more permanent elevation of the water. These studies of Whittlesey's were the earliest ones of marked value, and it will be noticed that he recognized some important features, such as the fact that the beaches are not level. Roy[1] found and described the beach terraces of Canada and ascribed them to inland lakes whose barriers had disappeared.

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[1] Coll. of the Hist. Soc. of New York, Vol. II, 1811, 94–96.

[2] Amer. Journ. Sci., 1, 1819, 116–125. This is opposed by Wells, same, 331–337, and by Bourne, same, II, 1820, 30–34.

[3] Trans. Geol. Soc., London, 2d Ser., I, 1824, 175–208.

[4] Phil. Mag., 2d Ser., V, 1829, 6.

[5] Travels in North America, Edinburgh, Vol. I, 1829, 167–170.

[6] Second Annual Rept. Geol. Survey of Ohio (Mather), 1838, 55.

[7] Outline Sketch of Ohio, 1848 (from Homer Historical Collections), 586–589; Amer. Journ. Sci., LV, 1848, 205–217; same, LX, 1850, 31–39.

[8] Foster and Whitney's Lake Superior Rept., Part 2, 1851, 270–273; See also Whittlesey, Smithsonian Contributions to Knowledge, XV, 1867, Article II, 17–22.

In New York, Hall[2] described the lake beaches and the ridge road, which he recognized as a true beach. The Erie terraces were also mentioned; and the terraced deltas of the Cayuga and Seneca valleys were explained as the result of former water levels, though he was doubtful as to the exact conditions then existing. Hayes[3] ascribed the beaches to ocean action, and Niagara gorge to the work of high and powerful tides. Lyell,[4] who visited the terraces in both New York and Canada, in the latter country in company with Roy, and in New York with Hall, noted their remarkable general levelness, and asked how the barriers supposed by Roy could have been removed without disturbing this levelness. To account for them he supposed that they were marine, and that the land had been elevated vertically above the sea. Some terraces were believed to be beaches, some bars; and this difference in origin, together with variations in supply, and in original surface contour, *plus* a slight difference in amount of uplift, he believed competent to account for the measure of irregularity noticed.

Lapham[5] describes the lake clays near Lake Michigan;

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[1] Phil. Mag , XI, 1837, 201-202.

[2] Second Rept. Geol. New York, 1838, 310-314; 348-350; Geol. of New York, 4th Dist., 1843, 342-354; 661-662.

[3] Amer. Journ. Sci., XXXV, 1839, 95-105.

[4] Phil. Mag., XXI, 1842, 548-555; Proc. Geol. Soc., III, 595; Phil. Mag., XXIII, 1843, 183-186; Amer. Journ. Sci., XLVI, 1844, 314-317; Travels in North America, Vol. I, 1845, 24; Vol. II, 85; 102-114. Much important work done in Canada by Roy, Fleming and others, and published upon in the Canadian Journal, Canadian Naturalist, and other Canadian publications, has not been examined, because I have not had access to sets of these Journals.

[5] Amer. Journ. Sci., 2d Ser., III, 1847, 90, 94.

and Agassiz[1] proposed to account for the terraces which line the shores of Lake Superior by assuming a change in the relative elevation of the lake and its shore, the change being in the land itself, not in the water. These changes were in the nature of paroxysms, causing frequent variations in level, and the cause for the paroxysms was believed to be the intrusion of dykes, of which large numbers occur on the shores of Superior.

Desor[2] advocated marine origin for the beaches of Superior and Ontario, pointing out that this view would also account for the various levels; for some were formed in more exposed places than others, and some, after having been formed, were destroyed, while others were really submarine terraces (œsars). The marine origin he believed to be indicated by the distinctly marine terraces of the St. Lawrence Valley, in which marine fossils occur; and the changes in conditions to those of the present he believed to have resulted from the uplift of the land. On the other hand Chapman,[3] agreeing with Roy, advocated fresh water origin and assumed that this fresh water was held in lakes raised in level by some eastern barrier.

LATER STUDIES.—With the studies of the Ohio Geological Survey there began a more scientific investigation of the shore lines, and Newberry,[4] as a result of his studies, attributed the beaches to a vast inland sea, which gradually contracted, for some unknown reason, possibly local subsidence, or erosion along channels of drainage. He suggested that the exact cause will be known only after careful future study, which calls for a detailed tracing of the several ridges. He gave one of the first clear arguments for the lacustrine origin of the lake ridges as opposed to the marine.

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[1] Proc. Amer. Assoc. Adv. Sci., I, 1849, 68–70; Lake Superior, Boston, 1850, 413–416; Amer. Journ. Sci., 2d Ser., X, 1850, 98–101.

[2] Foster and Whitney's Lake Superior Rept., Part I, 1850, 194–218; same, Part II, 1851, 232–270; Bull. Geol. Soc. France, VII, 1850, 623–630; Bull. Geol. Soc. France, VIII, 1851, 420–423.

[3] Phil. Mag., XXI, 1861, 428–435.

[4] Proc. Boston Soc. Nat. Hist., IX, 1862–3, 42–46; Geol. Survey Ohio. Report, 1869, 24–31; Annals New York Lyceum Nat. Hist., IX, 1870, 213–34; Amer. Nat., IV, 1870, 193–214.

Bannister,[1] describing the beaches of Lake Michigan near Chicago, referred them to a former level of Lake Michigan and described the outflow past Chicago, which is still recognized as a former outlet. This is one of the best early pieces of work upon the lake shores. Warren,[2] on the other hand, ascribed the beaches of the Red River valley, and some of the changes in the Great Lakes, to changes of land level.

It was as an assistant to Newberry that Gilbert[3] began his work upon the Great Lakes, a work which has produced such important results. He gave us the first detailed survey of a kind sufficiently accurate to be used in later mapping (Fig. 126). In connection with his work on the Maumee Valley,[4] Gilbert showed that the beaches must

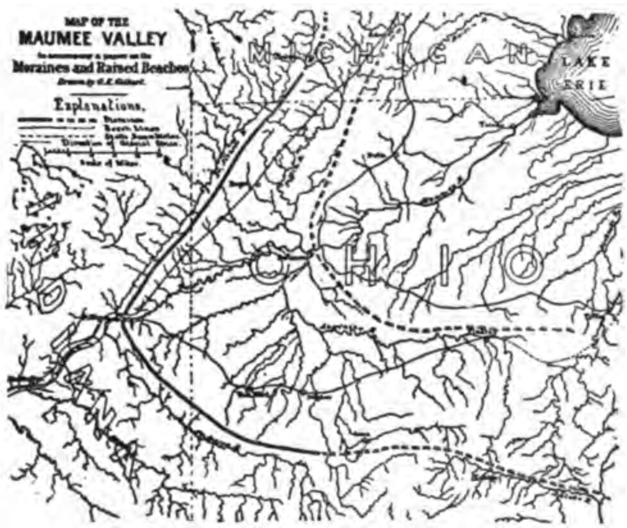

FIG. 126. The moraines and beaches of the Maumee valley (Gilbert).

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[1] Illinois Geol. Survey, III, 1868, 240–242.

[2] Annual Rept. Chief of Engineers, 1868, 307; Amer. Journ. Sci. CXVI, 1878, 416–431.

[3] Geol. Survey, Ohio, I, 1870, 488–495.

[4] Proc. New York Lyceum Nat. Hist., I, 1871, 175–178; Amer. Journ. Sci. CI, 1871, 339–345; Geol. Survey, Ohio, Vol. I, 1873, 537–56.

have been formed in lakes, because they converged toward the outlet channel past Fort Wayne, and that they have been tilted since their deposit. This tilting has later been used as proof that the change in land level was the cause for the change in outflow of the lakes and hence for the changes in the former lake levels. He also pointed out that, since the time when the lake water dropped from the level of the highest beaches, the level of Lake Ontario has been at least seventy feet lower than now. This paper of Gilbert's marks a very distinct advance in our knowledge of the Great Lakes history.

Another assistant to Newberry, Professor Winchell, was also engaged in the study of some of the Ohio terraces, some of the lower of which he referred to beach origin, others to glacial moraines, modified by water. The elevation of the lake waters is ascribed to the freezing up of all the outlets. Winchell inaugurated the policy of giving names to the various lake ridges.[1] The ridges were still further studied and described by Orton[2] and by Read[3] also of the Ohio Survey.

In a foot-note to Gilbert's paper, Newberry[4] makes the suggestion which Gilbert and most other workers have since accepted. He says, "In the discussion of these facts cited by Mr. Gilbert, and others of similar character, it should be remembered that the retreating glacier must have, for ages, constituted an ice dam that obstructed the natural lines of drainage, and may have maintained a high surface-level in the water-basin which succeeded it." Since then[5] this theory has been more fully stated; and Newberry, Gilbert and others have accepted it, first as a working hypothesis and later as a well-established explanation.

By the subsequent work of a number of writers a very large body of fact has been obtained. Chamberlin,[1] describing the beaches of Lake Michigan, stated that they were due to fresh water lakes, caused by land movement, the proof of this being the lack of uniformity in the level of the beach ridges.

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[1] Winchell, Proc. Amer. Assoc. Adv. Sci. XXI, 1872, 152–186; Geol. of Ohio, II, 1874, 56; 431-433.

[2] Geol. Survey of Ohio, I, 1873, 425–434; 438–449; 455–462.

[3] Geol. Survey of Ohio, I, 1873, 488–492; 516–519.

[4] Geol. Survey of Ohio, I, 1873, 552.

[5] Geol. Survey of Ohio, II, 1874. 21–65; 72–80; Proc. New York Lyceum Nat. Hist., II, 1874, 136–138; Geol. Survey of Ohio, III, 1873, 32-51; Proc. Amer. Phil. Soc., XX, 1882-3, 91-95.

Claypole[2] accepted the ice-dam theory and stated his views concerning the mode of retreat of the ice cap and the formation of the resulting lakes. Dryer[3] described in detail some of the beaches in Indiana, and Lawson[4] made a very complete statement concerning the beaches along the northern shore of Lake Superior. He questioned the glacial dam theory and proposed warping to account for the changes in outlet which have caused variations in level.

Spencer, one of the pioneers in the study of the Great Lakes, has gathered a large body of fact and added a great deal to our knowledge concerning the Great Lakes.[5] He ascribed the former high-water levels to marine action, though in this view he now stands practically alone. Not only does he refer to this origin beaches which others distinctly recognize as such, but also certain more elevated deposits of stratified drift which other observers do not consider to be beaches. It is Spencer's belief that there has been a very widespread and prolonged submergence of the land. He himself, together with other workers, has shown that there has been extensive warping,[1] which has aided in the final dismemberment of the great water bodies and formed the present Great Lakes. Many of the lake stages which Spencer has worked out, and to which he has given names, are now recognized and accepted, though in some cases the construction which he has placed upon facts differs from that placed upon them by others.

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[1] Geol. Survey of Wisconsin, II, 1877, 219–233.

[2] The Lake Age in Ohio (from Trans. Geol. Soc., Edinburgh), 1887. Edinburgh, 42 pp.

[3] Indiana Geol. Survey, 16th Report, 1889, 98–126; same, 17th Report, 1892, 114–134; 160–170; same, 18th Report, 1894, 17–32; 72–90. Studies in Indiana Geography, Terre Haute, 1897, 42–52.

[4] Twentieth Report, Minnesota Geol. Survey, 1891, 181–289.

[5] See Spencer, Proc. Amer. Phil. Soc., 1880–81, XIX, 300–337; same, 2d Geol. Survey Pennsylvania, Report QQQQ, 1881, 357–406; Proc. Amer. Assoc. Adv. Sci., 1881, XXX, 131–146; Proc. Amer. Assoc. Adv. Sci., 1882, XXXI, 359–363; Amer. Journ. Sci., CXXIV, 1882, 409–416; Geol. Mag., IV, 1887, 167–173; Amer. Nat., XXI, 1887, 168–171; Proc. Amer. Assoc. Adv. Sci., XXXVII, 1888, 197–199; Science, XI, 1888, 49; Bull. Geol. Soc. Amer., I, 1889, 65–70; Trans. Roy. Soc. Canada, VII, 1889, Sec. IV, 121–134; Bull. Geol. Soc. Amer., I, 1889, 71–86; Quart. Journ. Geol. Soc., 1890, XLVI, 523–533; Amer. Journ. Sci., CXL, 1890, 443–451; Amer. Geol., VI, 1890, 294; Amer. Journ. Sci., CXLI, 1891, 12–21; Amer. Geol., VII, 1891, 86–97; Amer. Geol., VII, 1891, 266; Amer. Journ. Sci., CXLI, 1891, 201–211; Bull. Geol. Soc. Amer., II, 1891, 465–476; Geol. Mag., VIII, 1891, 262–272; Bull. Geol. Soc. Amer., III, 1892, 488–491; 491–492; 494–495; Amer. Geol., XV, 1894, 135–136; Proc. Amer. Assoc. Adv. Sci., XLIII, 1894, 237–243; Amer. Geol., XIV, 1894, 289–301; Proc. Amer. Assoc. Adv. Sci., XLIII, 1894, 244–246; Amer. Journ. Sci., CXLVIII, 1894, 455–472; Amer. Nat., XXVIII, 1894, 859; Amer. Journ. Sci., CXLVII, 1894, 207–212; Proc. Roy. Soc., LVI, 1894, 145–148; Eleventh Report, Niagara Comm., 1895, Appendix, 126 pp. (Reprint of a number of papers); Popular Sci. Monthly, XLIX, 1896, 157–172; Proc. Amer. Assoc. Adv. Sci., XLIV, 1896, 139; Amer. Geol., XXI, 1898, 110–123. Because of the brief space available, it is impossible to state Spencer's views more fully or to refer more specifically to each of his contributions.

Taylor has made careful studies in the region around the shores of the various lakes, and has given us a body of fact of great importance.[2] From his studies he was at first led to explain the beaches as the result of marine submergence, which extended over the entire Great Lakes region into the Red River Valley, and northward to Hudson Bay (Fig. 127). The upper, earlier beaches, connected with overflow channels, were thought to have been caused by glacial dams; but the strongly developed beaches lower than these, were believed to have resulted from marine submergence, while certain recent changes were ascribed to tilting of the land, of which he states proof. In 1896, however, Taylor[3] announced his conversion to the glacial-dam theory, thus removing one of the two chief supporters of the hypothesis of marine origin.

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[1] As has been pointed out before, this warping was early recognized; but for an excellent general statement of this subject see de Geer, Proc. Boston Soc. Nat. Hist., XXV, 1892, 454–477; Amer. Geol., XI, 1893, 22–44.

[2] Amer. Journ. Sci., CXLIII, 1892, 210–218; Bull. Geol. Soc. Amer., V, 1894, 620–626; Amer. Geol., XIII, 1894, 316–327; same, XIII, 365–383; same, XIV, 273–289; Amer. Journ. Sci., CXLIX, 1895, 69–71; Amer. Geol., XV, 1895, 24; Amer. Journ. Sci., CXLIX, 1895, 249–270; Amer. Geol., XV, 1895, 100–120; 162–179; 394; same, 304–314; Amer. Geol., XVII, 1896, 253–257; same, XVII, 1896, 397–400: Inland Educator, II, 1896; Studies in Indiana Geography (Dryer), Terre Haute, Indiana, 1897, 90–110; Amer. Geol., XVIII, 1896, 108–120; Bull. Geol. Soc. Amer., VIII, 1897, 31–58; Amer. Journ. Sci., CLIII, 1897, 208; Amer. Geol., XIX, 1897, 392–396; Amer. Geol., XX, 1897, 65–66; 111–128; Proc. Amer. Assoc. Adv. Sci., XLVI, 1897, 201–202; Bull. Geol. Soc. Amer., IX, 1898, 59–84.

[3] Amer. Geol., XVII, 1896, 253–257.

Upham has added many facts to our knowledge of the postglacial history of the Great Lakes.[1] He has vigorously upheld the ice-dam theory, and has described the outlet of the higher Lake Superior waters, as well as the beaches around the shores of Lake Superior and elsewhere. He has also stated fully his interpretation of the succession of events connected with the withdrawal of the ice sheet from the Great Lakes' basins. Upham has, in addition, given us that classic monograph upon glacial Lake Agassiz, the most remarkable of the ice-dammed lakes.[2]

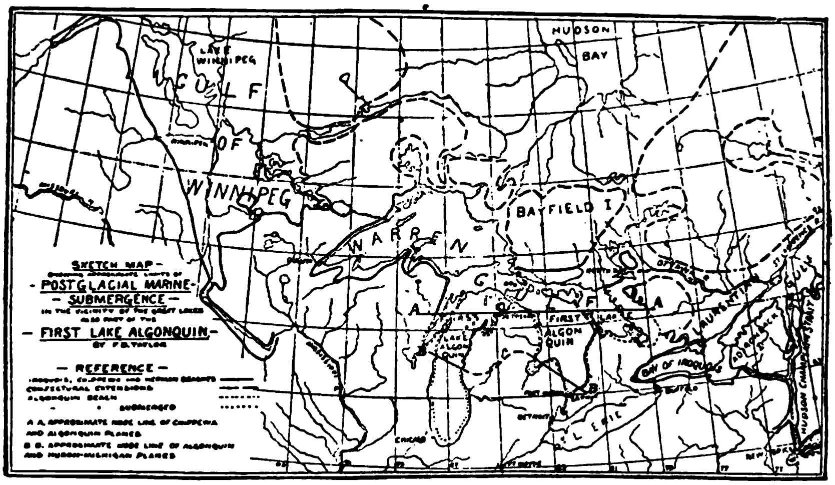

FIG. 127. Taylor's map showing the conception that he at first had concerning the supposed marine origin of the beaches of the Great Lakes' region.

Gilbert, who gave us the first full study of a portion of the Great Lakes' beaches, has by later investigation contributed a great deal to our knowledge of the eastern lakes.[1] He has traced the Ontario shore line in New York (Fig. 128), and pointed out its relation to the Mohawk outflow: he has proved that the land has been tilted since the beaches were formed, and that it is probably even now rising. Gilbert has also stated that Ontario was formerly lower than now, and that the volume of Niagara has changed as a result of the variation in outlet of the Great Lakes (Figs. 129 and 130). He has pointed out that the Ontario shore line disappears on the northern flank of the Adirondacks, as if there had been at that place some dam, like an ice dam, which held up the lake waters (Figs. 128 and 129). He has also proved the existence of former channels in New York, caused when the waters were escaping toward the Mohawk outflow.[2]

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[1] Proc. Amer. Assoc. Adv. Sci., XXXII, 1883, 230; Final Report, Minnesota Geol. Survey, II, 1888, 642-643; Bull. Geol. Soc. Amer., I, 1890, 563-567; same, II, 1891, 258-265; same, III, 1892, 484-487; Twenty-second Report, Minnesota Geol. Survey, 1894, 54-66; Nature, L, 1894, 198-199; Amer. Geol., XIV, 1894, 62-65; Proc. Rochester Acad. Sci., II, 1895, 196-198; Twenty-third Report, Minnesota Geol. Survey, 1895, 156-193; Bull. Geol. Soc. Amer., VI, 1895, 21-27; Amer. Journ. Sci., CXLIX, 1895, 1-18; Amer. Geol., XV, 1895, 396-399; Bull. Geol. Soc. Amer., VII, 1896, 327-348; Amer. Geol., XVII, 1896, 238-241; Amer. Geol., XVIII, 1896, 169-177; Monog. XXV, U. S. Geol. Survey, 1896, 255-264; Bull. Geol. Soc. Amer., IX, 1898, 101-110.

[2] Monog. XXV, U. S. Geol. Survey, 1896. In this references to his previous articles on Glacial Lake Agassiz can be found.

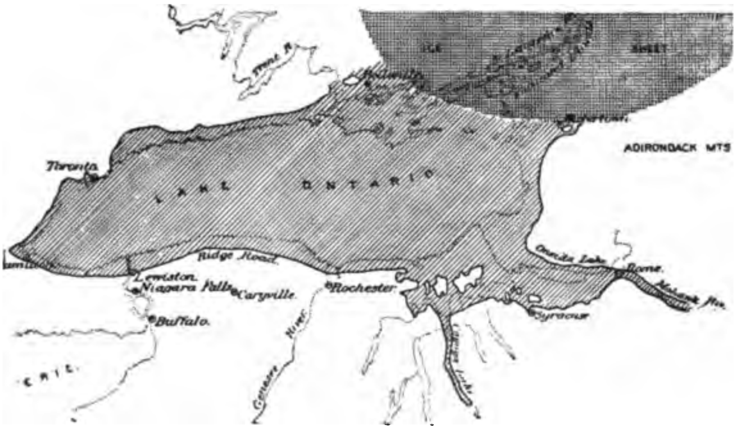

FIG. 128. Gilbert's map of glacial lake Iroquois.

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[1] See Science, VI, 1885, 222; Proc. Amer. Assoc. Adv. Sci. XXXV, 1886, 222–3; Science, VIII, 1886, 205; Forum, V, 1888, 417–428; Sixth Rept. Niagara Comm., 1890, 61–84; Smithsonian Rept. 1890, 231–257; Internat. Congress Geologists, 5th Session, (1891), Washington, 1893, 455–458; Bull. Geol. Soc. Amer., III, 1892, 492–493; same, 493–4; Amer. Journ. Sci. CL, 1895, 18; Bull. Geol. Soc. Amer., VI, 1895, 466; Amer. Geol., XVIII, 1896, 231; Physiography of the United States, 1896, 203–236; Bull. Geol. Soc. Amer., VIII, 1897, 285–286; Nat. Geog. Mag., VIII, 1897, 233–247; Eighteenth Annual Report U. S. Geol. Survey, 1898, 595–647.

[2] Bull. Geol. Soc. Amer., VIII, 1897, 285–286; see also Quereau, same, IX, 1898, 173–182 and Davis, Popular Sci. Monthly, 1894, 218–29.

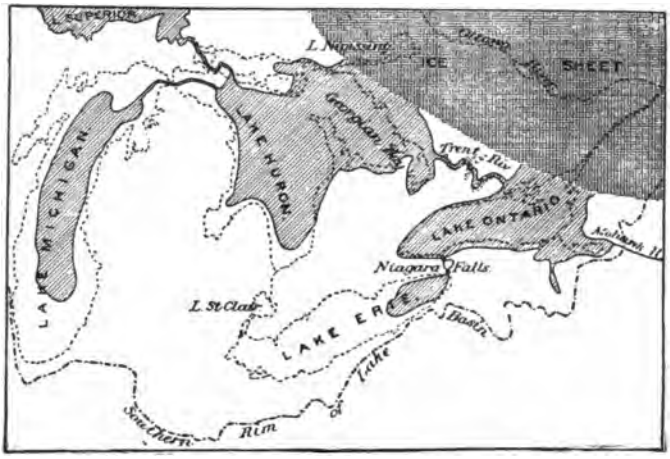

Fig. 129. Gilbert's map of the Great Lakes during the time when the St. Lawrence was ice-blocked.

Leverett[1] has done much painstaking work on the shore lines, especially of Erie and Michigan, and has added a great deal to the glacial dam theory by pointing out the relation between the frayed-out ends of beaches and the

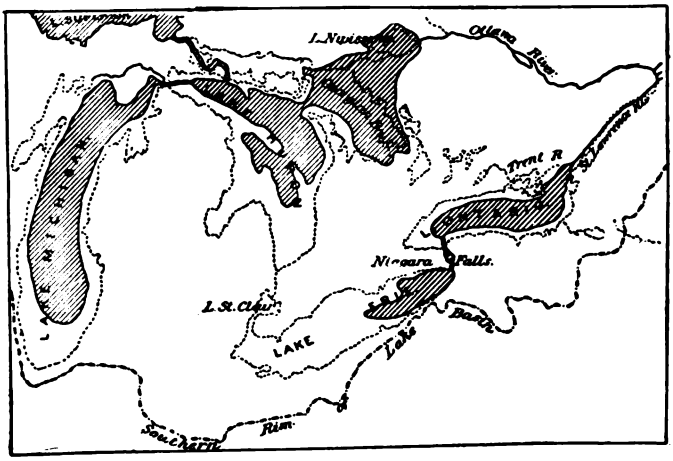

Fig. 130. Gilbert's map of Great Lakes after the ice had left the St. Lawrence and before the upper and lower lakes were finally connected.

glacial moraines. During his studies in Ohio, Gilbert had noted the disappearance of the Erie beaches toward the

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[1] Trans. Wisconsin Acad. Sci., VII, 1889, 177-192; same, VIII, 1892, 233-240; Amer. Journ. Sci., CXLIII, 1892, 281-301; same, CL, 1895, 1-20; Chicago Acad. Sci. (Geol. and Nat. Hist. Survey, Bull. 2) 1897, 55-86; Amer. Geol., XXI, 1898, 195-199.

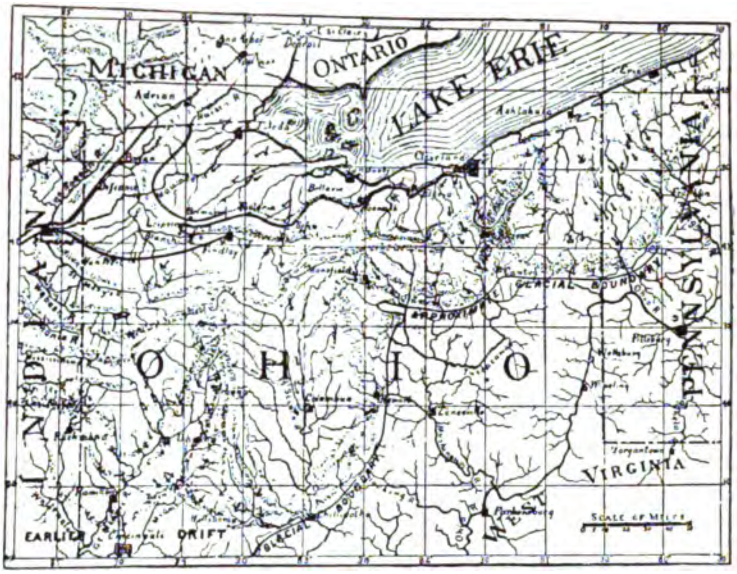

Fig. 131. Leverett's map of beaches and moraines of Ohio.

east, and he later proved that the same feature existed along the Ontario shore in the Adirondack region. Suggesting to Leverett the probability of the discovery of moraines where the beaches disappeared, moraines were looked for and found by Leverett, and their relation to the beaches stated (Fig. 131).

In New York Fairchild[1] is at work on the early stages of the glacier-dammed lakes; and by his studies he has proved the existence of numerous small lakes, with southern outlets, before their waters were united to cause the larger glacial lakes described by others.[2]

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[1] Bull. Geol. Soc. Amer., VI, 1895, 353–374; same, 462–466; same, VII, 1896, 423–452; same, VIII, 1897, 269–284; same, X, 1899, 27–68. See also Watson, New York State Museum Report 51, 1897, Part I, r55–r177.

[2] For other articles relating to the post-glacial history of the Great Lakes, see Claypole, Amer. Nat., XX, 1886, 856–862; Wright, Proc. Amer. Assoc. Adv. Sci. XXXVIII, 1889, 247; Bull. Geol. Soc. Amer., IV, 1893, 423–425; Davis, Amer. Geol. VI, 1890, 400; Amer. Geol., VII, 1891, 139; Popular Sci. Monthly, 1894, 218–229; Bell, Bull. Geol. Soc. Amer., IV, 1893, 425–427; Hill, Amer. Geol., XIV, 1894, 405; Shaler, Bull. Geol. Soc. Amer., VI, 1895, 151–152; Mudge, Amer. Journ. Sci. CL, 1895, 442–445; Tarr, Bull. 109, Cornell Univ. Agric. Experiment Station, 1896, 90–122; Winchell, Amer. Geol., XIX, 1897, 336–339; Elftman, Amer. Geol., XXI, 1898, 101–109; Brigham, Bull. Geol. Soc. Amer., IX, 1898, 183–210; Russell, Bull. Amer. Geog. Soc., XXX, 1898, 226–254.

CONSIDERATION OF THE THEORIES.—With this brief statement of the progress of ideas, and the references to the writings of the chief workers, I shall now attempt to state what seems to me to be the *most probable* postglacial history. Here again, as in the preceding chapter, it is to be understood that I make full use of all the literature referred to, as well as of some studies of my own, and from these draw such conclusions as appear to me to be warranted.

The raising of land barriers to the northeast, which was early suggested, is no longer held; and, if it were, it could be easily disproved, the best proof against it being the absence of beaches where the land barriers would have existed. The present lake ridges gradually disappear toward the east, as if the barrier or dam forming the lakes had been destroyed. The mere lowering of a land barrier would not destroy the beaches that were formed against it.

Concerning the marine hypothesis, the arguments in favor of it, so far as I am able to find, are first, the supposed discovery of evidence of high shore lines, so high that ice dams could not by any possibility explain them. It is to be noted that some of these, as those in the Cayuga and Seneca valleys, are directly connected with overflow channels, as shown by Gilbert, Wright,[1] Fairchild, and Watson, while others of the supposed marine deposits are ascribed by most glacialists to glacio-fluviatile origin, and not to marine action. Few geological hypotheses rest upon a more insecure basis than that of deep postglacial submergence of northeastern America, as upheld by Spencer and others. Until much better evidence of it is brought forward, it need not seriously influence our discussion concerning the history of the Great Lakes.

A second point, proposed by Spencer,[2] is that an ice dam is incapable of holding back such volumes of water. Such an argument is not very strong, especially if there is good evidence that ice dams *did* hold back water bodies of large size. Most glacialists believe that a great and deep ice sheet, occupying the entire St. Lawrence Valley, is a sufficiently strong dam to hold a large lake in check; and this belief is greatly strengthened by the almost certain evidence of the existence of such a dam.

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[1] Proc. Amer. Assoc. Adv. Sci., XXXVIII, 1889, 247.

[2] Geol. Mag., VIII, 1891, 262-272.

A third point advanced in favor of the marine hypothesis is the fact that there *are* marine beaches in the Hudson, Lake Champlain, Ottawa and St. Lawrence valleys,[1] in which marine fossils are found. Against the correlation of these distinctly marine beaches with those of the Great Lakes is the fact that, although the marine deposits and the lake beaches are both well developed in their respective localities, there has been no direct connection traced between them, although it has been attempted by several observers. No marine fossils have been discovered in the lake beaches, although such fossils abound in the marine beaches further down the St. Lawrence Valley; but this absence of fossils is explained by the advocates of the marine hypothesis on the assumption that this great arm of the sea contained either fresh or brackish water, or else that the marine fossils did not have time enough to enter it from the sea.[2]

The existence of marine forms at present living in the Great Lakes[3] is also argued in favor of marine invasion; but if this proves anything, it proves merely that salt water entered the basins at one stage, which may be readily granted, without attempting to explain all the beaches by marine action. Moreover, if this marine fauna of the lakes is due to an incursion of the sea while the beaches were forming, it is rather remarkable that no remains of such a fauna have been discovered in the present beaches.[1]

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[1] See Merrill, Trans. New York Acad. Sci., IX, 1890, 78–83; Amer. Journ. Sci., CXLI, 1891, 460–466; Davis, Proc. Boston Soc. Nat. Hist., XXV, 1891, 318–34; Hitchcock, Geol. of Vermont, Vol. I, 1861, 93–167; Baldwin, Amer. Geol., XIII, 170–184; Logan, Canadian Geol. Survey, 1863, 896–930; Dawson, Amer. Journ. Sci., CVIII, 1874, 143; The Canadian Ice Age, Montreal, 1894 (with reference to the literature); Ells, Bull. Geol. Soc. Amer., IX, 1898, 211–222. This is by no means a complete list of references on this subject; but from these other references may be obtained.

[2] Spencer, Proc. Amer. Assoc. Adv. Sci., XXXI, 1882, 359–363; Geol. Mag., VIII, 1891, 262–272; Amer. Geol., XV, 1894, 135–136.

[3] Hitchcock, Proc. Amer. Assoc. Adv. Sci., XIX, 1870, 175–181; Stimpson, Amer. Nat., IV, 1870, 403; Smith, Annual Rept. U. S. Fish Comm., 1870–3, 643–644; Nicholson, Ann. and Mag. Nat. Hist., Ser. IV, X, 1872, 276–285; Chamberlin in Geikie's Great Ice Age, 3d Ed. 1894, 769.

There seems very little in favor of the marine hypothesis, and there are numerous facts against it, and in favor of ice dams, which have never yet been satisfactorily answered. One of the strongest objections to the marine hypothesis is that the beaches end toward the east, as if the waves had worked there against some dam, like ice, which could not record their work after the ice had gone. It is true that Spencer claims that the beaches *do not* end as reported,[2] and that the moraine accumulations near their ends *are not* in reality connected with them. It is too early to pronounce a final opinion upon this latter disputed point, for naturally the ends of beaches in an ice-dammed lake will not be abrupt, but gradual and difficult to locate definitely; and, moreover, moraines built during the recession of an ice sheet, while the front stood in a lake, might well fail to be formed, or else might have been formed with a very indefinite development.

With reference to Spencer's claim that the beaches *do not* end as reported, it is noteworthy that in one case where Spencer has claimed to have continued the beaches beyond the supposed end, both Gilbert and Taylor,[3] working in the field in company with Spencer, have not been able to recognize his beaches, although they were pointed out by their discoverer. Gilbert and Taylor explain by other causes than wave action the deposits assumed to be beaches by Spencer. It seems fair, therefore, to hold to the belief that the beaches *do* come to an end where claimed, since all the workers in the field, excepting one, have reached this conclusion as the result of their observations; and if this conclusion is correct, then the ice-dam theory is strongly supported. Indeed, the very fact that Spencer himself admits that the connecting beaches, if they really exist, are indistinct, while elsewhere, both on the seaward and landward side, they are strongly developed, argues against the marine hypothesis.

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[1] Since this was printed, there has appeared an important paper by Coleman (Bull. Geol. Soc. Amer., X, 1899, 165–176), in which it is announced that *fresh water* fossils have been discovered in the elevated beaches at Toronto.

[2] Amer. Geol. VI, 1890, 294; Bull. Geol. Soc. Amer., III, 1892, 488–491; 494; Amer. Geol., XXI, 1898, 110–123. See Leverett's reply to last in Amer. Geol., XXI, 1898, 195–199.

[3] See Spencer, Bull. Geol. Soc. Amer., III, 1892, 488–491; 494. See also reply by Gilbert, same, 492–493; also Taylor, Amer. Geol., XIX, 1897, 392–396.

Then, also, the overflow channels furnish an unanswered and apparently unanswerable argument against the hypothesis that the beaches were formed in arms of the sea; for it seems evident that *rivers have flowed out* through these channels from the landward toward the seaward side; and, as Davis states, it is difficult to understand how a river could flow from one arm of the sea to another. The shore lines converge toward these outlets from the north and are strongly developed on the lake side, but have not been shown to exist on the opposite side, and in some cases are *certainly* not present there. Where, then, are the shore lines that must have been formed on the *southern* side of the St. Lawrence divide if the sea covered that land? Although Spencer has attempted to answer this objection of Davis's, his reply does not seem satisfactory.[1]

Everything indicates that the former high levels of the Great Lakes were due to ice dams, as first suggested by Newberry; and the proof of this theory is so strong that opinion is now all but unanimous in favor of its acceptance. It is nearly established as a fact, though for a while should probably be considered still as a working theory. Accepting this, then, as a probable explanation, I will briefly state the history of change from the first beginning of the withdrawal of the ice sheet to the present condition of the lakes, so far as this history has been worked out, following in this discussion chiefly the interpretations of Gilbert and Taylor.[2]

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[1] See Davis, Amer. Geol., VI, 1890, 400; same, VII, 1891, 139; Spencer, same, 266; Bull. Geol. Soc. Amer., III, 1892, 491–492; 495; Gilbert, same, 493–494; Spencer, Proc. Amer. Assoc. Adv. Sci., XLIV, 1896, 139.

[2] Gilbert, Sixth Annual Rept. Niagara Comm., 1890, 61–84; Physiography of United States, 1896, 203–236; Taylor, Studies in Indiana Geography (Dryer), Terre Haute, 1897, 90–110.

THE ICE-DAMMED LAKES.—During its southernmost extension the glacier covered all the basin of the Great Lakes system. As the ice sheet encroached upon the region, it must have formed numerous marginal lakes, though of these no records have yet been discovered. When the ice cap finally began to withdraw, it retreated northward and northeastward, uncovering first of all the southern portions of the drainage area. In these north-sloping stream valleys, tiny lakes existed, growing in size as the ice dam took successively more and more northerly positions. The map (Fig. 132) shows the approximate location of three of the largest of these lakes. Within the State of New York such lakes existed at a later time in the Genesee, Seneca, Cayuga and other valleys.

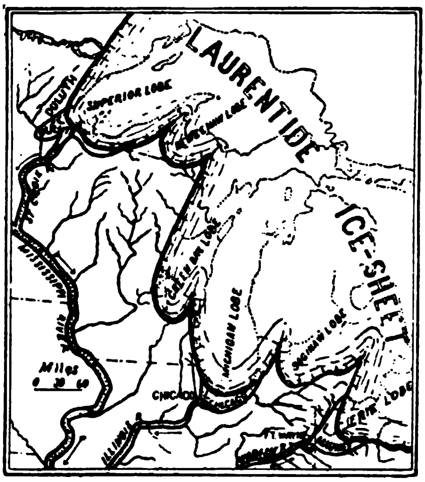
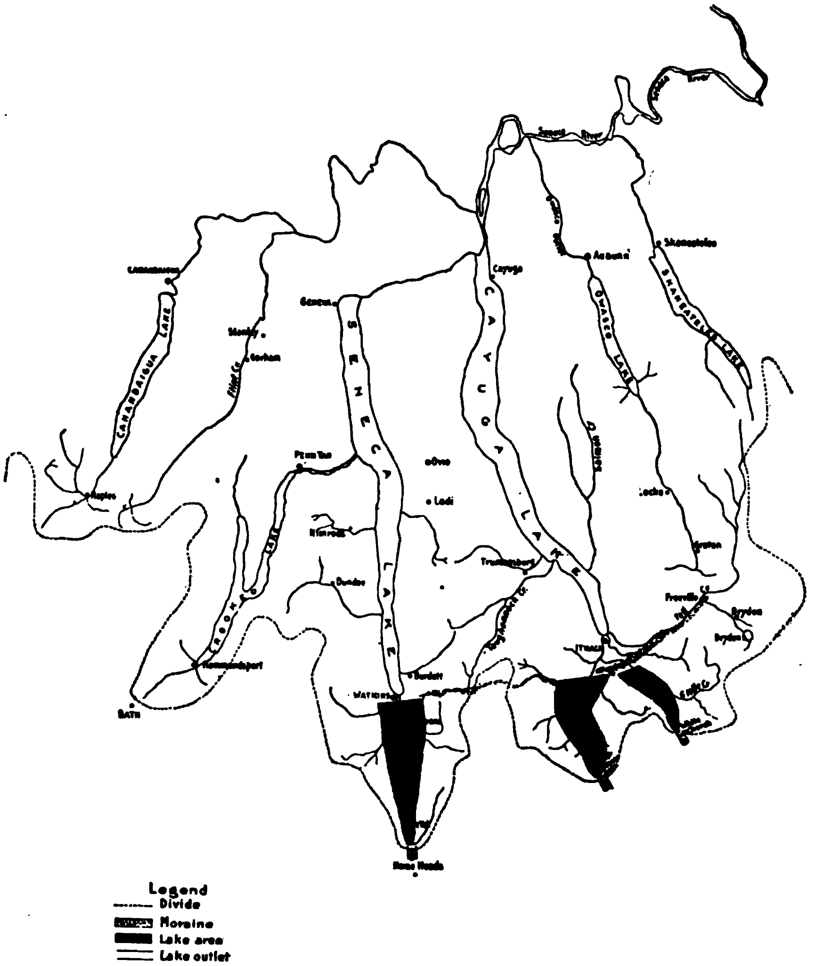


FIG. 132. Taylor's map of local ice margin lakes.

As the ice dam melted further back, lower outflows were discovered, and the level of the lake waters fell. At the same time some of the small marginal lakes successively coalesced and flowed out through one outlet instead of two or more. For instance, note how, as shown in Figures 132 and 136, the Maumee Lake expanded to form Lake Whittlesey, and, escaping across the lower Michigan peninsula into the enlarged Lake Chicago, found an outflow into the Illinois River past Chicago.

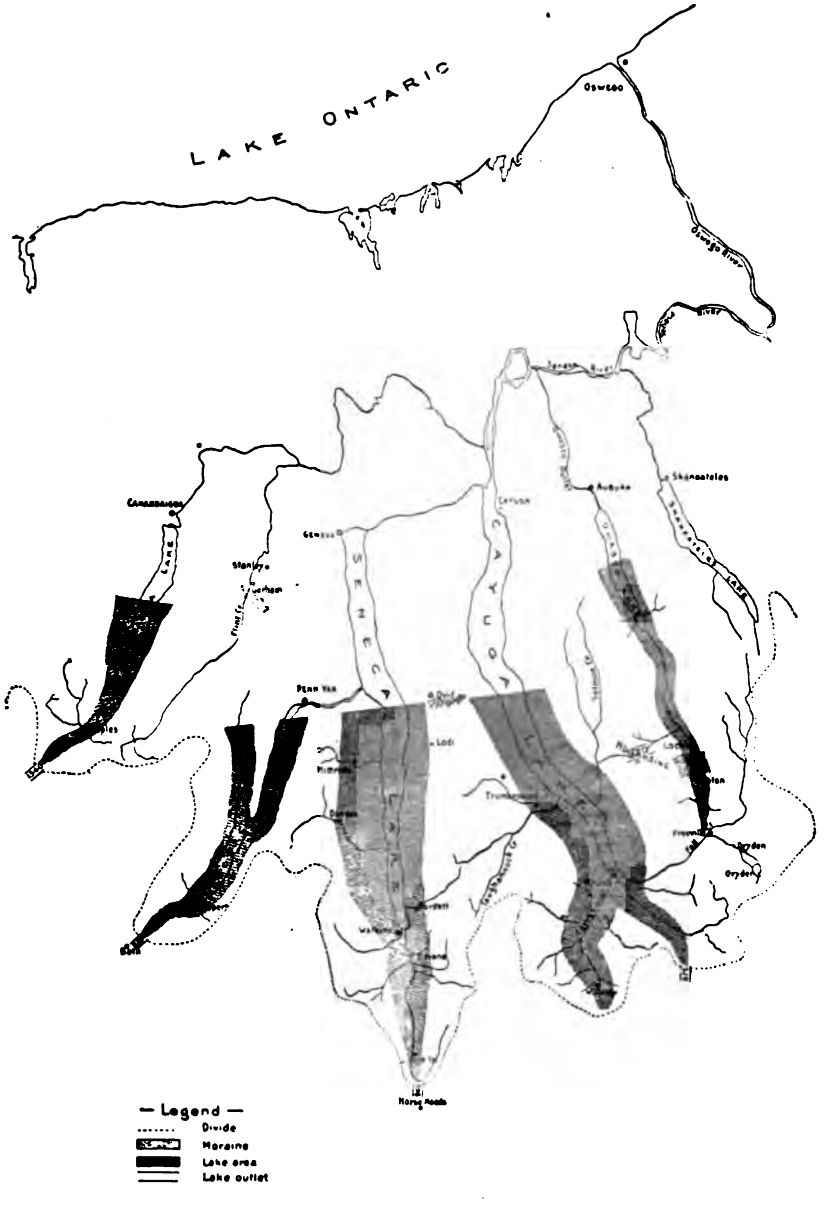
During the early part of this stage of coalescing marginal lakes, New York was largely under cover of the ice; but in time the same stage visited this State. At first there were numerous tiny lakes (Fig. 133), which enlarged and coalesced, abandoning one outlet after another (Fig. 134), until the several lakes of the Finger Lake region



Map Showing the Areal Extent of Glacial Lakes West Danby and Brookton and the Incipient Stage of Glacial Lake Watkins.

By Thomas L. Watson.

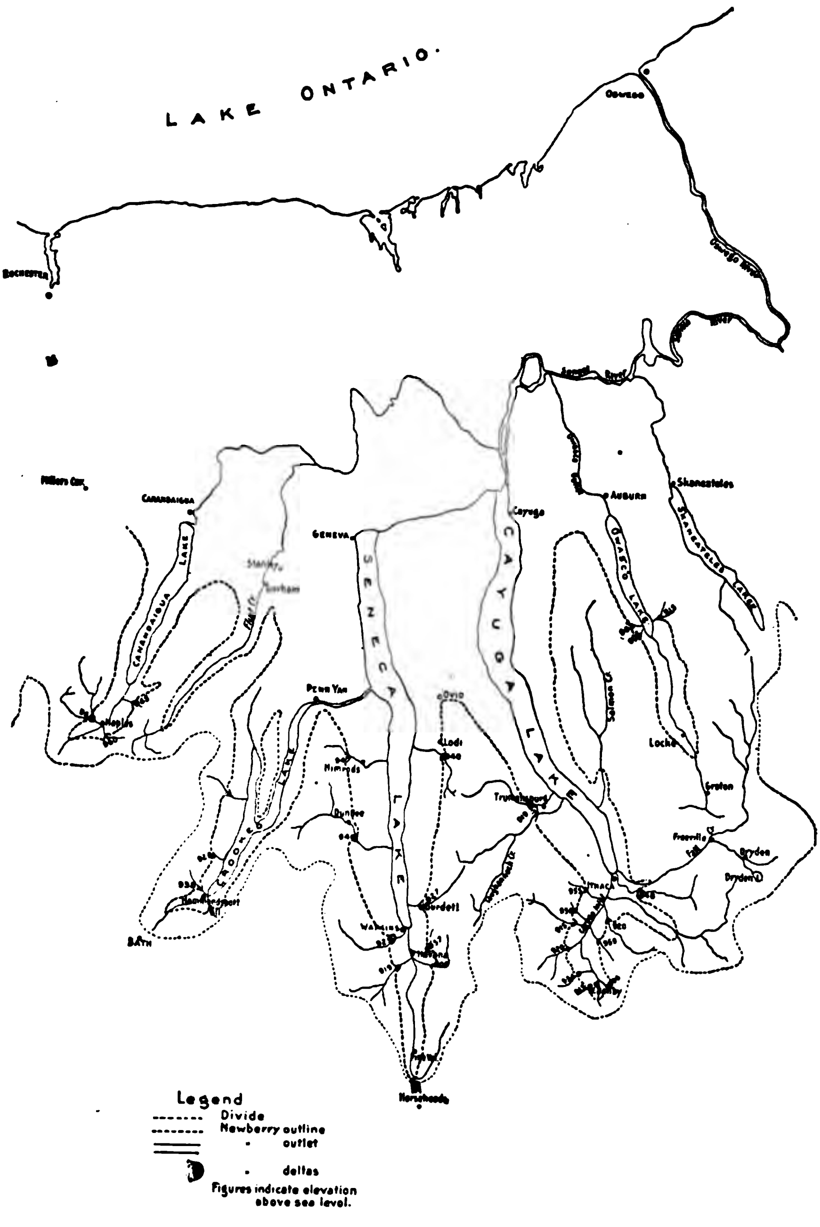
Fig. 133.



Map Showing Approximately the Maximum Levels of the Local Glacial Lakes Occupying the Present Finger-Lake Valleys.

BY THOMAS L. WATSON.

FIG. 134.



Map Showing the Approximate Areal Extent of Glacial Lake Newberry.

By Thomas L. Watson.

Fig. 135.

united into one branching lake, with an outflow over the Seneca Lake divide, forming what Fairchild proposes to call Glacial Lake Newberry (Fig. 135). As this enlarged, it is probable that the drainage finally found its way westward into the Chicago outflow, though of this there is not yet definite proof.[1]

Finally the ice withdrew from the Mohawk Valley, thus opening a lower outflow than that past Chicago, and then the waters of all the lakes escaped into the Atlantic through the Hudson (Figs. 129 and 137). Before this stage was reached the water from the western lakes found its way into the Mohawk through temporary overflow channels, between the ice and the land, at levels well above the Mohawk divide near Rome. Since one of the walls of this temporary river system was the ice front, it follows that the channels were not located along the natural drainage lines of the present. Thus, temporary east-flowing streams cut channels across the hills and left various other records of their existence.[2] It was during this stage that some of the lower delta terraces which cling to the sides of the valleys of the Finger

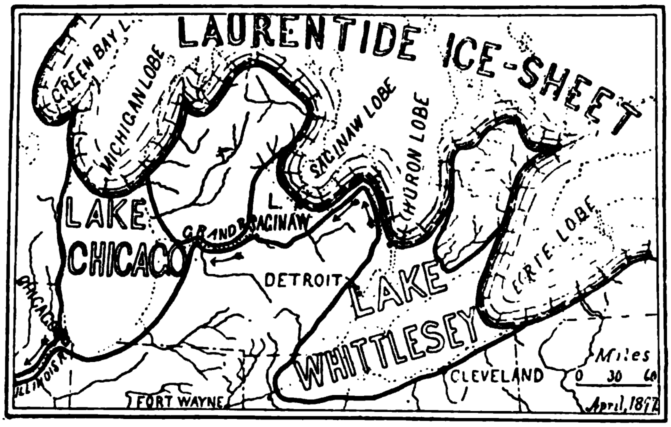


FIG. 136. Taylor's map of the lake stage when the eastern waters combined with the western and outflowed past Chicago.

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[1] See Fairchild, papers referred to on page 250. Also see Watson, New York State Museum, Report 51, 1897, Part I, r55-r117.

[2] See Gilbert, Bull. Geol. Soc. Amer., VIII, 1897, 285-286; Quereau, Bull. Geol. Soc. Amer., IX, 1898, 173-182.

Lakes were formed, when the water in them was falling to successively lower levels, as new outlets were being discovered upon the retreat of the glacier.

Just before the water began to escape by this means toward the east, there existed a continuous marginal lake, broadening westward, and with an outflow through the Chicago channel. This expanded lake, made by the union of Lakes Chicago, Saginaw and Whittlesey, together with other marginal waters further east, is known as Lake Warren. At one time it included a sheet of water parallel to the southern Erie shore, and probably also the waters that occupied the Finger Lakes region immediately after the abandonment of the Seneca divide, which had controlled the level of Glacial Lake Newberry. The easternmost extension of Lake Warren is not definitely known, and the connection with the Finger Lakes is merely a probability, based upon a knowledge of the fact that the waters of Lake Warren *did* extend eastward until they finally found an outflow through the Mohawk.

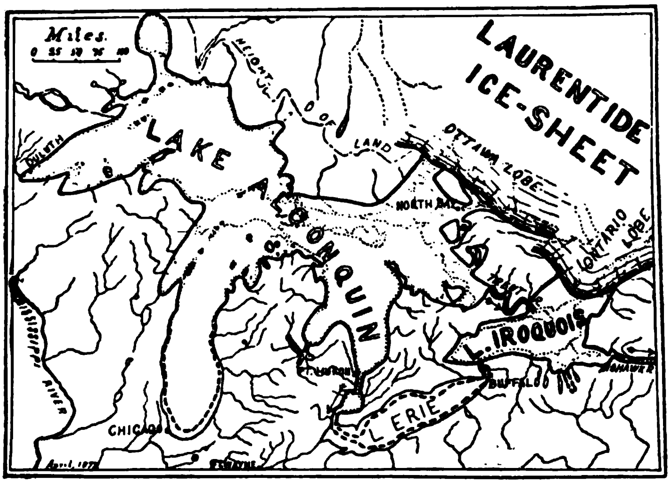

FIG. 137. Taylor's map showing that stage in the lake history when Lake Algonquin emptied into Lake Iroquois through the Trent (see also Fig. 129).

With the uncovering of the Mohawk, the Lake Warren waters flowed eastward, and the level fell, until, finally,

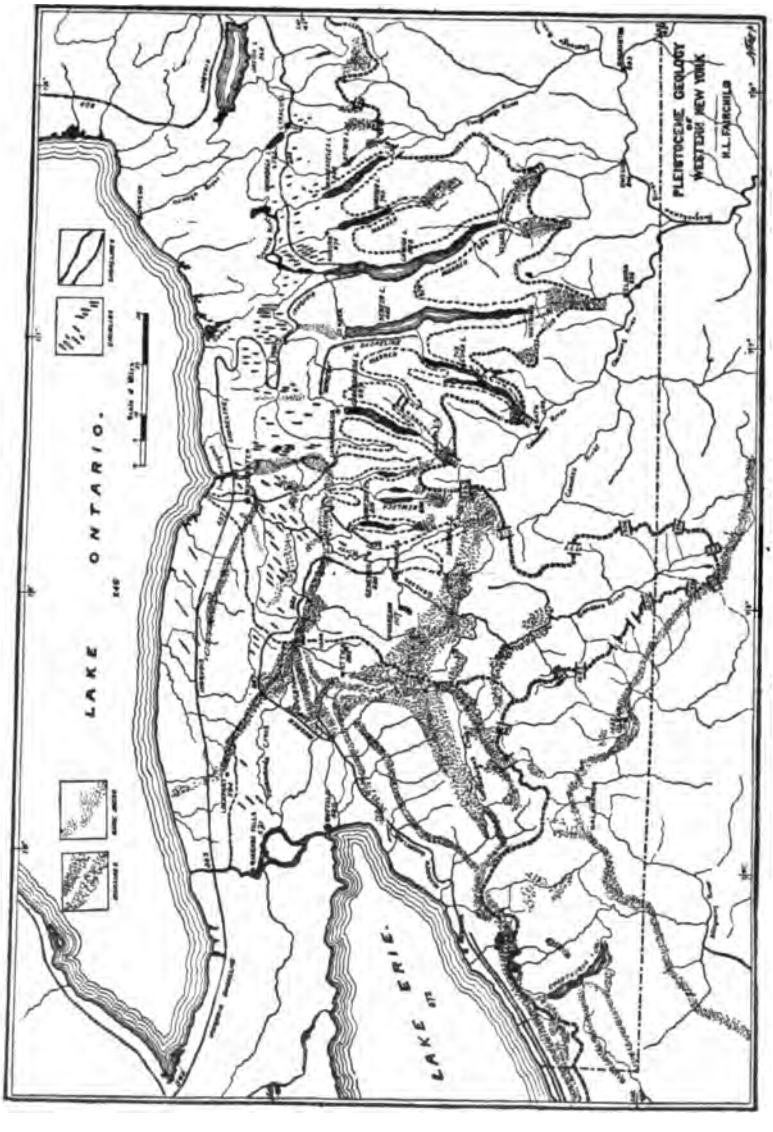
LAKE ONTARIO
LAKE ERIE
Scale of Miles
PLEISTOCENE GEOLOGY OF WESTERN NEW YORK
H. L. FAIRCHILD

FIG. 138.

the entire Erie basin was uncovered. Niagara River then began to flow when the water level in the Ontario basin fell below that of Lake Erie. The outflow of the upper Great Lakes was then, as now, through the Detroit-Lake St. Clair channel into Lake Erie; and the Niagara River was then, as now, a large river. The three upper lakes were at that time united to form Lake Algonquin (Fig. 137); but, as the ice front withdrew still further, it uncovered the Trent River Valley, which, because of the northward depression of the land at that time, was then lower than the Detroit channel, so that the waters of Lake Algonquin were then withdrawn from the Lake Erie overflow, and the size of Niagara was greatly reduced thereby. The waters from the upper Great Lakes then flowed directly into the expanded Ontario without first passing through Erie. The expanded Ontario has been called Glacial Lake Iroquois (Figs. 128 and 137), and its overflow was through the Mohawk, because the St. Lawrence outflow was still ice-filled.

It will be noticed on the map (Fig. 137) that the shore lines of Lake Algonquin, in the Michigan region, disappear below the lake waters north of Chicago, and also that the outflow of the upper Great Lakes is marked as being through the Trent River, although we know that this is now higher than the Detroit outlet, which was then abandoned in favor of the Trent. The proof of this change is found in the convergence of the beaches toward the Trent River and the evidence that a large river formerly occupied it. The tilting of the beaches is in harmony with all the other evidence, and it therefore seems certain that an uplift of the land was in progress during the time of the retreat of the ice.

All the beaches of the lakes are somewhat tilted, although the oldest are most affected. This tilting, which on the Iroquois beaches of New York is about five feet per mile in a northeasterly direction, has elevated many beaches high above the level of the present lakes. One passes upgrade in going along these shore-line deposits in a northeasterly direction. That this uplift was actually in progress while the lakes existed is shown by the difference in inclination of the older and younger shore lines.

The uplift seems also to have shifted the outflow of Lake Algonquin once more to the Detroit channel, thus causing the Trent River to be abandoned and Niagara River to become enlarged once more.

Finally the ice withdrew from the St. Lawrence Valley, so that the level of Lake Iroquois fell, but not to the present level of the Thousand Island outflow, for the valleys of the St. Lawrence, Hudson, Lake Champlain, Ottawa, and probably also Lake Ontario, were then occupied by the sea, because of the northeasterly depression of the land. The proof of this depression comes from the discovery of marine beaches with marine fossils in the St. Lawrence, Ottawa and Champlain Valleys. Where there is no direct proof, there is some evidence in favor of extending the area of the sea beyond that indicated by Taylor (Fig. 139), so as to admit the salt water into the Lake Superior basin.[1]

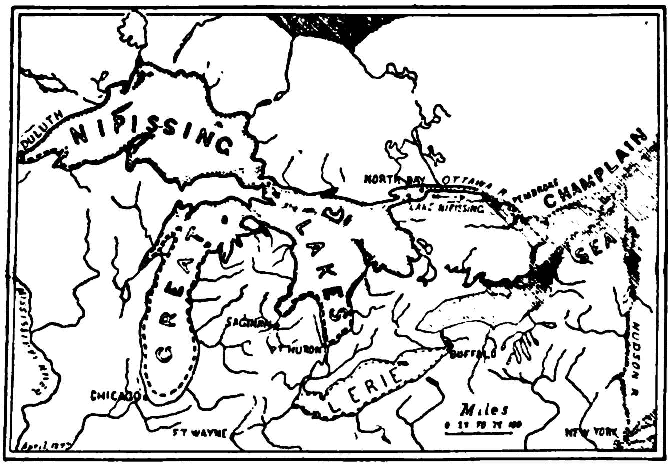

FIG. 139. Taylor's map of the Great Lakes during the encroachment of the ocean waters into their basin.

By the withdrawal of the glacier, the valley now occupied by the Nipissing Lake and the Mattawa and Ottawa

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[1] See references, p. 252.

Rivers was uncovered; and, in the depressed condition of the northern land, this was so much lower than the Detroit Channel that the volume of Niagara was again reduced to that of a small stream draining only the Lake Erie basin (Figs. 130 and 139). Taylor believes that this period, when the Nipissing or upper Great Lakes were coalesced and had an outflow through the Ottawa into the St. Lawrence sea, was a very long one, for he finds that the Nipissing shore lines are the most strongly developed of the elevated beaches. During this stage Ontario was apparently occupied by an arm of the sea, Erie by a small lake in its eastern end, because of the tilting of the basin toward the northeast, and the three upper lake basins by a single lake, united by the same channels as at present, only slightly larger and deeper, as were the lakes themselves in their northern part. Because of the depression of the land toward the north, the water surface of the southeastern ends of the Nipissing Lakes was lower than the present lake surfaces, and the northern and eastern portions higher. These points, as well as the others mentioned, have been more or less well established by the careful and detailed study of the beaches, mainly carried on by Taylor, as described in the articles referred to on page 246.

The land continued to rise, lifting the Ontario basin above the sea, and establishing the Thousand Island overflow. At first, owing to the depressed condition of the land in the northeastern portion, Lake Ontario did not reach as far westward as now (Fig. 130), and the Niagara River flowed for several miles over land that is now covered by the lake water. The proof of this is found in the existence of a submerged continuation of the Niagara River channel over the lake bottom, and a delta off the mouth of the present river. For the same reason, as has been stated, Lake Erie was smaller than now, and confined to the eastern end; but, as the land was elevated in the north, the lakes assumed more and more nearly their present form; and during the progress of this uplift, the outflow was once more shifted to the Detroit channel, because the Nipissing outlet was elevated higher than the present outflow of the upper lakes past Detroit. The Detroit channel has since then been continuously occupied, and Niagara has since then had approximately its present volume. If the uplift is still in progress, as suggested by Spencer,[1] and as Gilbert has attempted to demonstrate,[2] there may in the future be still another change in the direction of the outflow of the Great Lakes, this time past Chicago. Such clear evidence as the above telling of the numerous and often tremendous past changes, which is so clear, should offset skepticism concerning the possibility of still other future changes. The land is unstable, and the future has many changes in store, and perhaps the disappearance of Niagara may be one of these.

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[1] See references on p. 245.

[2] Nat. Geog. Mag., VIII, 1897, 233-247; Eighteenth Annual Report U. S. Geol. Survey, 1898, 595-647.

CHAPTER IX

NIAGARA

DESCRIPTION.[1] — The Niagara River emerges from Lake Erie, near Buffalo, a full-born river, and in its course to Lake Ontario, a distance of about 30 miles, it receives only slight additions to its supply of water, mainly from the small Tonawanda and Chippewa Creeks. It is unlike most rivers also in the fact that it is essentially free from sediment load. The river leaves Erie as filtered water; and, thus robbed of cutting tools, under normal conditions would be able to perform little work of valley formation. It would be able to act chemically, but could do almost no mechanical work, notwithstanding its immense volume.[1]

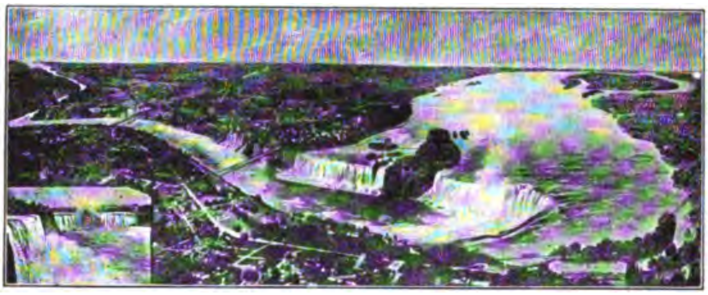

FIG. 140. A bird's-eye view of Niagara river showing the broad, quiet upper course, the cataract and the gorge below.

As has been shown on page 12, and as is evident from the accompanying maps (Figs. 4 and 141), the region between Lakes Erie and Ontario consists of two plains, divided by an escarpment 200 feet high. The upper plain passes beneath Lake Erie, the lower beneath Lake Ontario, where it is faced by a sublacustrine escarpment. The escarpment separating the upper and lower plains is steeply sloping and is underlaid by the very massive Niagara limestone, which forms the surface rock of the upper plain to a point a short distance above the crest of the cataract (Fig. 142). This Niagara limestone has a total thickness of about 140 feet, but is only about 20 feet thick at the escarpment, because its upper layers have been removed by denudation. At the Falls (Fig. 154) the limestone is from 60 to 80 feet thick. Beneath this are shales and sandy layers, all bedded as nearly horizontal sheets, dipping gently southward toward Lake Erie at the rate of about 35 feet per mile. The

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[1] See Capt. Basil Hall, Travels in North America, Vol. I, Edinburgh, 1829, 177–208; Gilbert, Sixth Annual Rept. Niagara Reservation Commission, 1890, 61–84; Physiography of United States, American Book Co., New York, 1896, 203–236; Grabau, Bull. New York State Museum No. 45 (Vol. 9), 1901.

[2] Blackwell (Amer. Journ. Sci., XLVI, 1844, 67), estimates the volume of Niagara to be 22,440,000 cubic feet, or 1,402,500,000 pounds per minute.

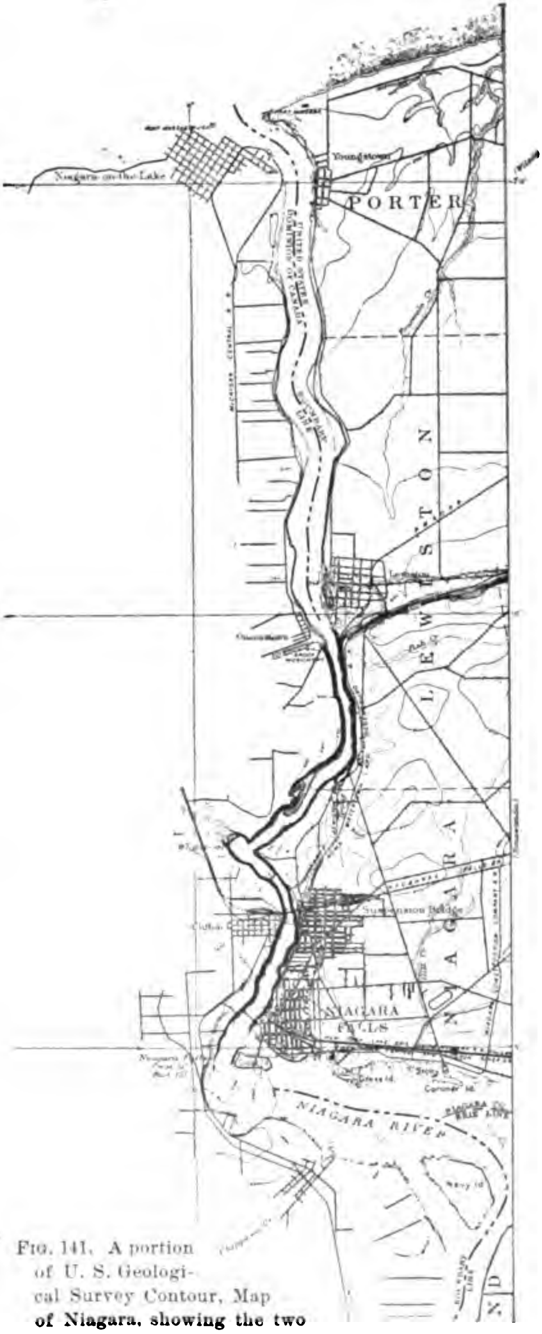

FIG. 141. A portion of U. S. Geological Survey Contour, Map of Niagara, showing the two plains and the escarpment at Lewiston.

rock above the Niagara limestone, and underlying the Erie plain, consists of the Salina shales; and near Buffalo there is another bed of limestone, the Corniferous (Fig. 142)

The Niagara River crosses this section from Erie to Ontario, commencing as a broad river, with gentle course excepting where it crosses the Corniferous limestone, at which place the current becomes rapid. For fifteen miles it flows almost on the surface of the plain, at one place even dividing into two channels with the large Grand Island between. Without cutting tools the river has not been able to carve a noticeable valley. Then, about a half or three-quarters of a mile above the Falls, the current quickens (Fig. 157), and soon the river becomes transformed to "a broad, roaring rapid, tumbling over one ledge after another with tumultuous haste."[1]

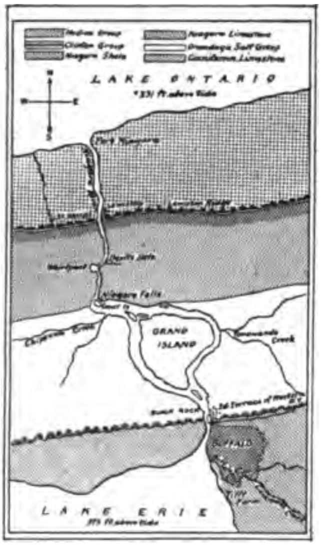

FIG. 142. Geological map of vicinity of Niagara (after Gilbert).

The water then tumbles over the brink of the Falls (Fig. 151) from a height of 517 feet above sea-level down to the level of 357 feet, giving a fall of about 160 feet.[2] Above the upper rapids the river is broad, and the depth from 10 to 22 feet. At the cataract it is divided by Goat Island into two falls (Fig. 148), the smaller being the American, the large the Canadian or Horseshoe, over which the bulk of the water flows, with a depth, according to Schermerhorn, probably averaging less than 4 feet, though without doubt reaching 20 feet at the apex.

From the base of the Falls, for a distance of about

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[1] Gilbert, Physiography of United States, New York, 1896, 208.

[2] Schermerhorn (Amer. Journ. Sci., CXXXIII, 1887, 278–284), states that the fall is 155 feet high on the Canadian side, 161 feet near Terrapin Tower, and 169 feet near the eastern side of the American Falls.

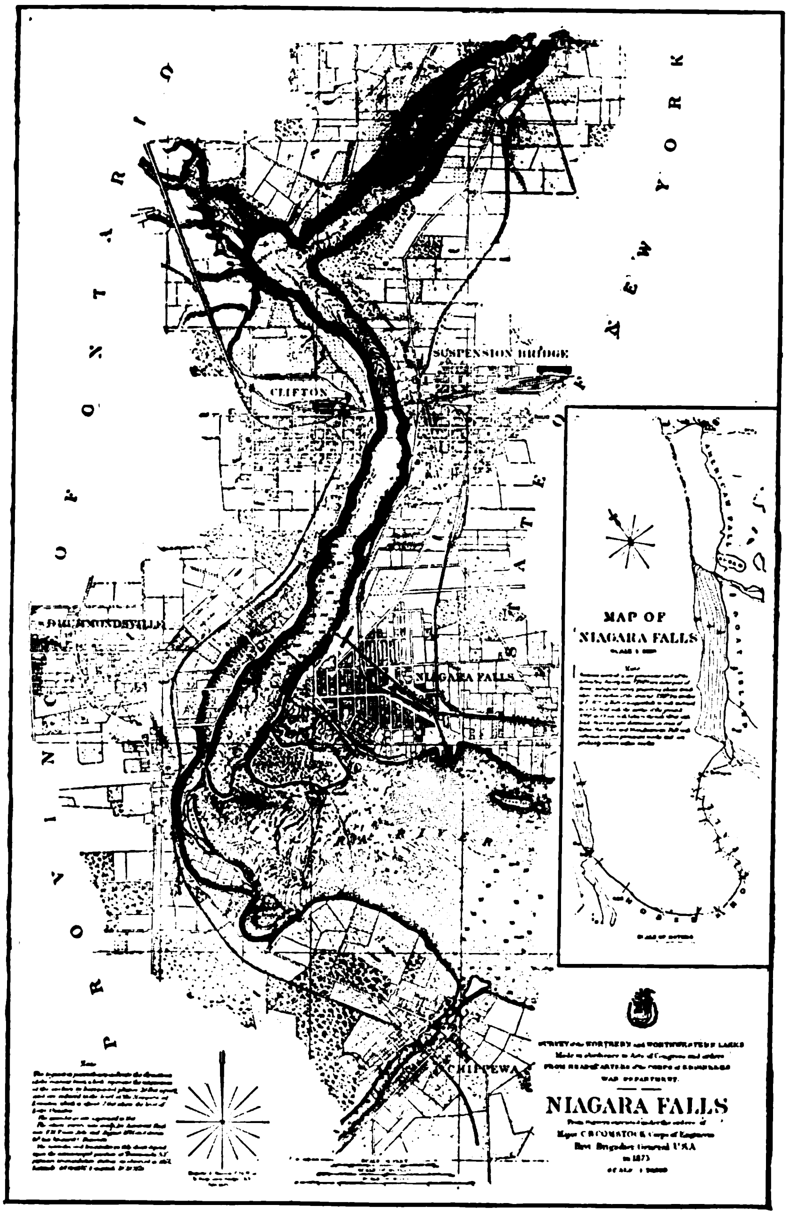

Fig. 143. Map of Niagara Falls and vicinity.

seven miles, the river occupies a deep channel cut through the Niagara limestone into the underlying shale, limestone and sandstone beds, to the depth of 200 or 300 feet, and with a width commonly between 200 and 300 yards. Throughout its distance, excepting in one place, the gorge walls are capped by the massive Niagara limestone, while beneath this are beds of shale with one or two strata of harder rock. Near the base of the cliff is a talus (Figs. 146, 159 and 160) in which numerous large boulders of the Niagara limestone form a prominent part, having fallen there from the cap rock of the gorge walls.[1] From the Falls nearly down to the railway bridges, the gorge is broad and the water fairly quiet, excepting near the Falls, where the river swirls around under the disturbance of the tremendous vertical descent at the cataract. In this stretch of quiet water the soundings reveal a depth in one place of 189 feet, and in several other places of 160 feet (Fig. 143).

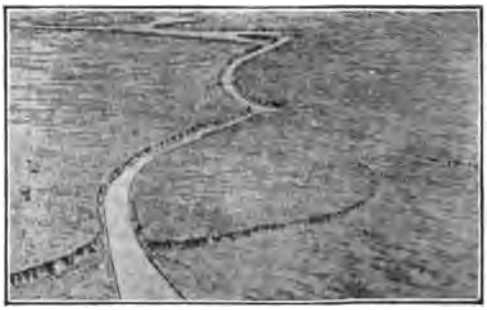

FIG. 144. The two plains and escarpment, with the whirlpool — St. David's channel on the right (after Gilbert).

Near the railway bridge the gorge narrows quite abruptly, and the current quickens until it is transformed to a furious mass of whirling water, forming the Whirlpool Rapids (Fig. 158). In the bed of this there are apparently large blocks of the Niagara limestone, which throw the river surface into great billows. Here the river depth is evidently shallow.

Below this the gorge broadens out again and forms a great elbow, known as the Whirlpool (Figs. 141, 143, 144 and 147), where the water is again deep. At this place the gorge

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[1] These landslides are often noticed; see, for instance, Claypole, Nature, XXXIX, 1889, 367. A large fall of limestone also occurred in the spring of 1899.

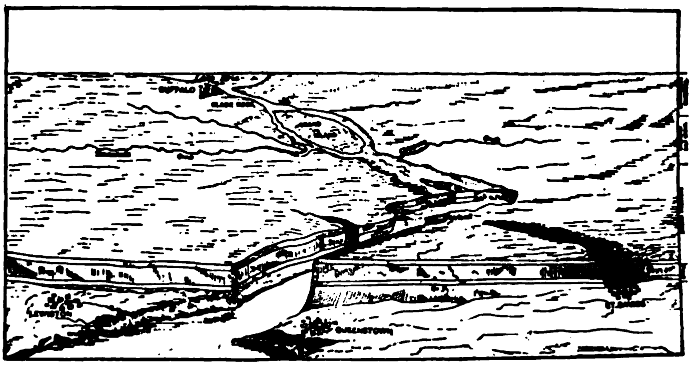

Fig. 145. A bird's-eye view of Niagara (after Gilbert).

turns nearly at right angles, after which it narrows and broadens in one or two places, being especially narrow at Foster Flats. Throughout this lower half of the gorge the current is prevailingly rapid, and the depth evidently much less than that above the Whirlpool Rapids. Gilbert[1] makes the following estimate of the depth of the river at various places. At the Whirlpool Rapids, 35 feet; at the outlet of the Whirlpool, 50 feet; opposite Wintergreen Flat, 35 feet; and below Foster Flat, 70 feet. The depth of the Whirlpool is estimated to be about 150 feet.

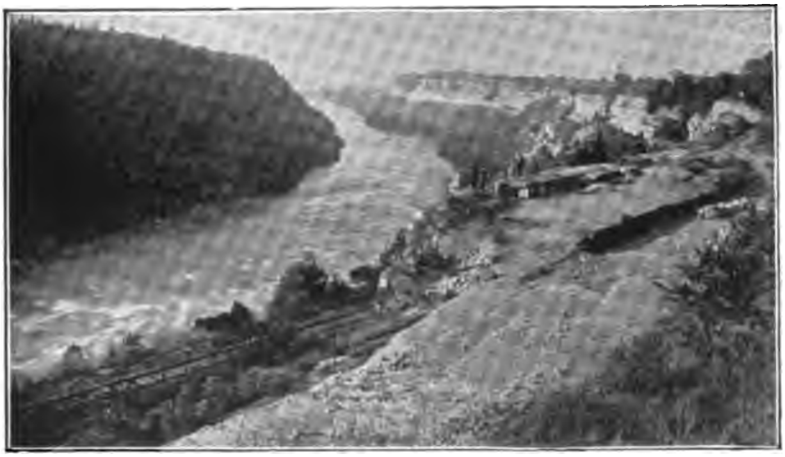

Fig. 146. The gorge of Niagara, with the capping of Niagara limestone plainly shown on the right.

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[1] Amer. Geologist, XVIII, 1896, 232-233.

After a passage of about seven miles through the gorge (Figs. 146, 147, 158 and 160), alternately expanding and contracting, and with the current now moderate and now rapid, and in places even violently rapid, the river emerges from its cañon (Fig. 159) and passes peacefully across the lower plain, in a valley somewhat broader than the gorge, and bounded by low banks rising to the level of the lower plain.

Throughout its gorge the river is everywhere bounded by rock walls, excepting in one place, the Whirlpool, where, on the Canadian side, there is a drift-wall, with a slope much more gentle than commonly (Fig. 143), and down which a tiny stream passes into the Niagara. In line with this drift-filled depression, the rock-capped Queenstown escarpment itself is interrupted by a drift-wall near the village of St. David's (Fig. 145). There seems to be a buried valley here extending from the Whirlpool to St. David's. This is called the St. David's channel, and it has apparently had considerable influence upon the history of the Niagara River.

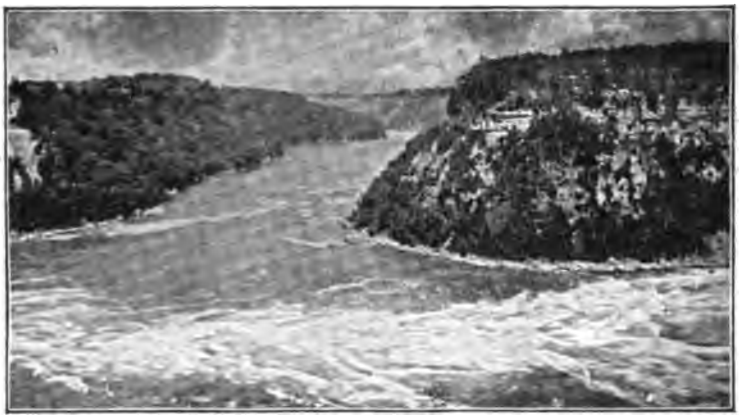
FIG. 147. The outlet of the Whirlpool, where the river bends sharply.

While the river is not rapidly deepening its valley in the upper 15 miles, nor in most of its course below the cataract, it has long been evident that very active work of valley formation is in progress at the cataract itself.

Since Niagara is a post-glacial stream, having had its birth at the time when the upper Great Lakes abandoned the Chicago outlet for the Mohawk (p. 262), it has seemed to many that it would be possible to use Niagara as a measure of this part of geological time. Much study has therefore been given to the Niagara River. The gorge has evidently been *formed* by the river itself, and the rate of present wear is known; but the problem proves more complex as studies are extended. Perhaps the best way of treating the subject clearly, and with a measure of completeness, is to consider first of all the contributions of the principal students of the problem, and then to discuss some of the results.

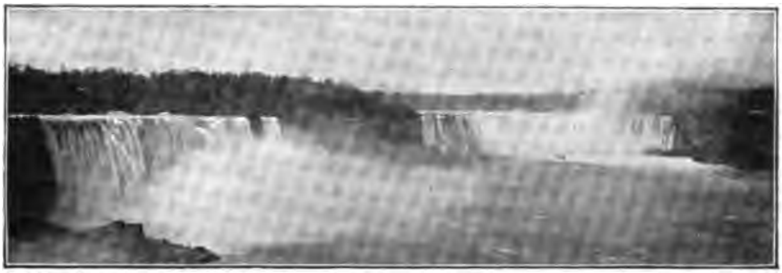

FIG. 148. The American (on the left) and Canadian (on the right) Falls.

EARLY VIEWS.—While Niagara was mentioned as early as the time of Champlain, it seems to have been first described, from actual visit by Europeans, by Father Hennepin,[1] whose account is interesting but unimportant and grossly exaggerated (Fig. 149). Various other early travelers[2] described the Falls, but one of the best early accounts is that by Kalm (Fig. 150).[3] While the first accounts are merely descriptive, more than a century ago there were speculations concerning the history of the cataract and gorge. We find, for instance, that Wm. Maclay,[1] in his journal for February 1, 1790, proposed to fix the age of the world by means of Niagara. He noted that the gorge is about seven miles long, and that the Falls had retreated some 20 feet in the 30 years since Sir Wm. Johnson visited them, making the age of the earth at least 55,440 years, a startling result for those times, as is shown by M'Causlin's discussion of Niagara three years later.[2] He considered the question whether the Falls had really retreated and stated that to have formed the gorge in the space of 5,700 years (the age of the earth) they must have retreated much more rapidly than they appear to have done since he began to study them. In the same publication, Ellicott[3] announced his decision that Niagara had retreated through the seven miles of the gorge.

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[1] A New Discovery of A Vast Country in America, London, 1698, 24–26.

[2] See for instance, Dudley, Phil. Trans., VI, 1722, 69–72; Lancourt, Travels through the United States of North America, etc., in the Years 1795, 1796 and 1797, London. Vol. I, 1800, 390–394; John Mande, Visit to the Falls of Niagara in 1800, London, 1826; Volney, View of the Climate and Soil of the United States of America (French edition, 1803), Philadelphia, 1804; Bigelow, Journal of a Tour to Niagara Falls, 1805, Boston, 1876; F. Hall, Travels in Canada, Boston, 1818, 230–240; Darby, A Tour from the City of New York to Detroit in the Michigan Territory, New York, 1819, 162; Schoolcraft, Narrative, Journal of Travels, etc., 1821, 33.

[3] Gentleman's Magazine, XXI, 1751, 15–19; another good account is by Weld, Travels through the States of North America, 1795, '96 and '97, London, 1799, 308–323.

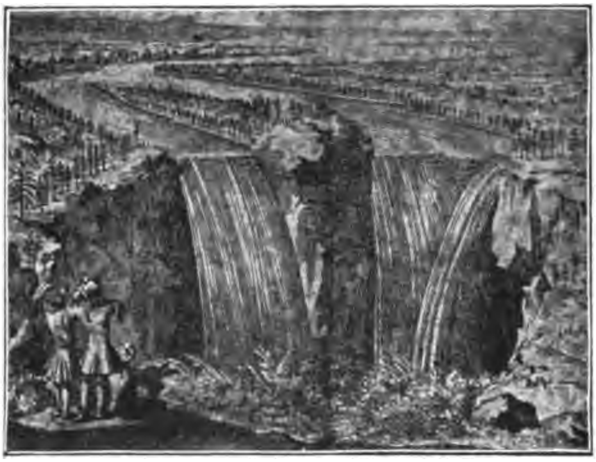

FIG. 149. Hennepin's picture of Niagara.

In 1819 Atwater[4] assumed that Niagara has cut its gorge, thus draining the lake that he believed once stretched over a part of Ohio. That this was not so was argued by Wells[1] and by Bourne.[2] In the same magazine Foot[3] stated that the Falls were once at Lewiston. Eaton[4] gave the first geological section showing the structure at the Falls. Next comes an article by Geddes,[5] who argued against the conclusion that Niagara had carved its gorge.

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[1] Journal of Wm. Maclay, Appleton, New York, 1890, 190.

[2] Trans. Amer. Phil. Soc., 1793, 17-24; see also Enys' Visit to Niagara, 1787; Report on Canadian Archives, 1886, CCXXVI-CCXXXIII, by Douglas Brymner.

[3] Trans. Amer. Phil. Soc., IV, 1799, 227-229.

[4] Amer. Journ. Sci., I, 1819, 116-125.

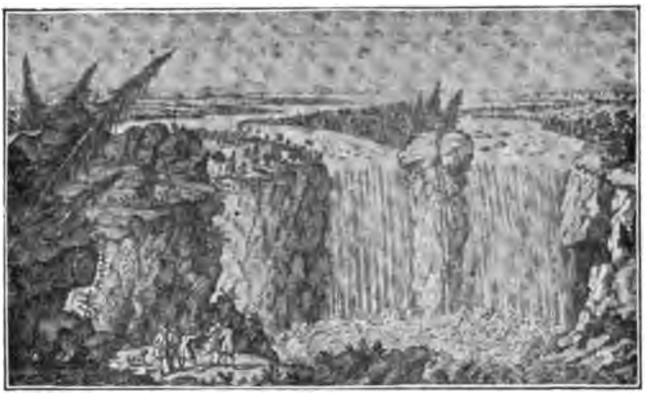

Fig. 150. A view of Niagara from Kalm's paper.

The most important early work upon Niagara was that done by Capt. Basil Hall[6] who went behind one of the smaller Falls, and noted the violent blasts of air caused by the falling spray, pointing out its importance in undermining the Niagara limestone by removing the friable shales.[7] His description of the river is so excellent that I quote from it:

"The river Niagara, which flows from Lake Erie into Lake Ontario, is unlike any other river that I know of. It

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[1] Amer. Journ. Sci., I, 1819, 331–337.

[2] Amer. Journ. Sci., II, 1820, 30–34.

[3] Amer. Journ. Sci., IV, 1822, 35–37.

[4] Geological and Agricultural Survey of District Adjoining the Erie Canal, Part I, 1824, 149.

[5] Amer. Journ. Sci., XI, 1826, 213–218; Trans. Albany Inst., I, 1830, 55–59.

[6] Amer. Journ. Sci., XIII, 1828, 364–368; Travels in North America, Vol. I, 1829, Edinburgh, 177-208; Forty Etchings made with the Camera Lucida in North America, in 1827 and 1828, Edinburgh, 1829.

[7] See also Mitchell, Observation on the Geology of North America (bound with Cuvier's Essay on the Theory of the Earth, New York, 1818), 351–360

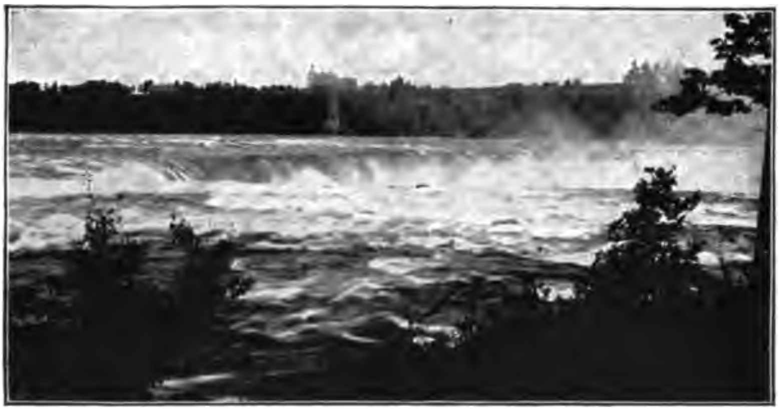

Fig. 151. The crest of the Horseshoe or Canadian Fall.

is a full-grown stream at the first moment of its existence, and is no larger at its mouth than at its source. Its whole length is about thirty-two miles, one-half of which is above the Falls, and the other half lies between them and Lake Ontario. During the first part of its course, or that above the tremendous scene alluded to, this celebrated river slips quietly along out of Lake Erie, nearly at the level of the surrounding flat country. So nearly so, indeed, that if by any of those chances which swell other rivers, but have no

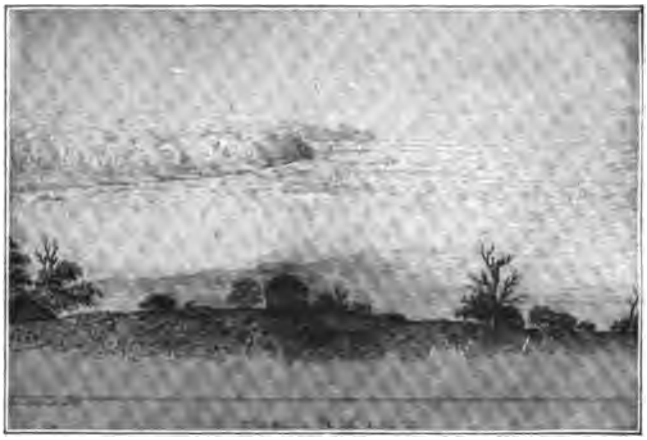

Fig. 152. Niagara in 1827, from a camera-lucida drawing by Capt. Basil Hall.

effect here, we could suppose the Niagara to rise perpendicularly eight or ten feet, the adjacent portion of Upper Canada on the west, and of the State of New York on the east, would be laid under water.

"After the river passes over the Falls, however, its character is immediately and completely changed. It then runs furiously along the bottom of a deep, wall-sided valley, or huge trench, which seems to have been cut into the horizontal strata of the limestone rock by the continued action of the stream during the lapse of ages. The cliffs on both sides are at most places nearly perpendicular, without any interval being left between the cliffs and the river, or any rounding of the edges at the top; and a rent would seem a more appropriate term than a valley. Above the Falls, therefore, that is, between them and Lake Erie, it will be understood, there is literally no valley at all; as the river flows with a gentle current, and almost flush, as seamen call it, or level with the banks; while below the cataract, the bed of the river lies so deep in the earth that a stranger, unprepared for these peculiarities, is not aware of there being any break at all in the ground, till he comes within a few yards of the very edge of the precipice. In point of fact we did drive for some distance on the American side of the valley or ravine of Niagara, across which we were looking, all the while, at the scenery in Canada, without knowing it, and without being in the least degree

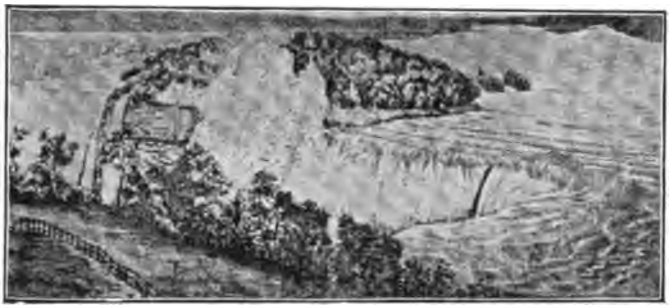

FIG. 153. Niagara in 1832, from a camera-obscura drawing by Ransford.

conscious that such a strong natural line of demarcation was interposed between us and that province."

He pointed out that the gorge is now being noticeably extended, giving instances of recent retreat, and argued that the gorge itself had been formed by the same slow work. This description of Basil Hall's marks the real beginning of the scientific study of Niagara, and its importance deserves full recognition.

Henry[1] stated that the Niagara Gorge had been cut out by the irresistible current of the river. In the same year Bakewell[2] published his first discussion of Niagara, in which he pointed out that there had been a retreat of about 50 yards in 40 years, at which rate the age of the gorge is 9,856 years, though he states clearly that, owing to the variations in the nature of the rock and in the water supply, this estimate could not be considered accurate. Bakewell also recognized the true cause for retreat previously so clearly stated by Capt. Hall.

Conybeare,[3] however, opposed the view that Niagara had cut its gorge. Fairholme,[4] on the other hand, accepted the idea of retreat and placed the rate at 4 feet a year; and, making various assumptions, considered the age of the gorge to be 4,500 years, placing the beginning at the Mosaic deluge. Rogers[5] pointed out the weakness of this argument and also opposed Bakewell's view, and questioned whether the Falls were ever at Lewiston. Rogers noted the existence of fresh-water shells in the gravels of Goat Island, now accepted as evidence of the former greater height of the river when the Falls were standing further down stream than now.

Dr. James Hall[6] stated that the cataract was once at Lewiston and pointed out the fact that, since the strata which determine the Falls are dipping toward the south, that is up stream, the height of the Falls will diminish as they retreat up stream. In fact, when they have retreated two miles further the shale beneath the limestone will have dipped so far into the ground that the Falls will then be located entirely upon the Niagara limestone, thus removing one of the chief causes for the present cataract. When that time arrives, the Falls will change to a series of rapids. The statement sometimes made that Niagara Falls will retreat until Erie is drained is therefore unfounded.

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[1] Trans. Albany Inst., I, 1830, 101.

[2] Mag. Nat. Hist., III, 1830, 117-130.

[3] Phil. Mag., IX, 1831, 266-267.

[4] Phil. Mag., 3d Ser., V, 1834, 11-25; see also Fairholme, New and Conclusive Physical Demonstrations both of the Fact and Period of the Mosaic Deluge, London, 1837; see also Gibson, Amer. Journ. Sci., XXIX, 1836, 201-213.

[5] Amer. Journ. Sci., XXVII, 1835, 326-335.

[6] Second Rept. Geol. Survey of New York, 1838, 371-373.

The same author later[1] gives a very full description of Niagara, and a convincing argument in favor of the view that the Falls were once at Lewiston. However, with the clearness characteristic of his scientific mind, he recognized the importance of definitely determining the rate of retreat; and for that purpose he had made for future comparison an instrumental survey of the Falls which has been of the greatest service in later studies of Niagara Falls.

Hall showed that the history of Niagara had not been uniform, but that the recession was probably at first rapid, the Niagara limestone being then much thinner than at the site of the present Falls. He pointed out too, that when Niagara first began, there may very well have been three falls instead of one great cataract, one located upon the Niagara limestone, the other two on the still lower hard layers, which have now dipped out of sight some distance north of the crest of the present Falls.

About this time there were a number of articles on Niagara containing little of importance. Hayes,[2] considering the lake beaches as marine, ascribed Niagara gorge to the scouring action of the high and powerful tides. Featherstonhaugh[3] affirmed that Niagara had carved its gorge and showed the relation of the hard and soft strata to this work. Allen[4] stated that 167,862,420 gallons of water, or

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[1] Hall, Geol. Survey New York, Fourth Dist., 1843, 383–404; Reprinted in Eighth Rept. Niag. Comm. Rept., 1892, 67–89; Boston Journ. Nat. Hist., IV, 1843–44, 106–134.

[2] Amer. Journ. Sci., XXXV, 1839. 95–105.

[3] Proc. Brit. Assoc. Adv. Sci., 1844, 45–46.

[4] Amer. Journ. Sci., XLVI, 1844, 67–73.

701,250 tons, pass over Niagara Falls every minute, representing 4,533,334 horse power.

Lyell's visit to America[1] included a study of Niagara, from which some important facts were added. He brought forward strong arguments in favor of the theory of retreat of the falls, both present and past, and, assuming a rate of about one foot a year, reached the conclusion that the gorge is about 35,000 years old. While assuming uniformity of retreat, he recognized that there were causes which would prevent such uniformity, so that Niagara is not a good chronometer. He believed that the river flowed into the sea during a submergence of the land, which he thought to be proved by the elevated beaches which he assigned to marine action. There were at first three falls, according to Lyell, and the river work has varied with the retreat of the Falls. He also recognized, as pointed out by Hall, that the cataract will be destroyed when it has retreated up stream about two miles further. One of the important arguments for retreat brought forward by Lyell is the presence of river gravels, not only at Goat Island, as previously recognized, but resting on the limestone cap of the gorge, four miles below the Falls, *proving* at least that much recession. He pointed out that all this had happened so recently that animals still existing were then living on the earth, and that if so recent an event has required so long a time, a vast period of time is required for the preceding geological events.

This description of Lyell's is one of the most important early contributions; but one of his most valuable results was the discovery, in company with Dr. Hall, of the drift-filled valley at the Whirlpool and the recognition of its connection with the break in the escarpment at St. David's.[2] Since that time the Whirlpool-St. David's gorge has figured in the discussion of Niagara.

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[1] Travels in North America, Vol. I, 1845, 27–53; Vol. II, 90; also Eight Lectures on Geology, 1842, 43–47; Proc. Geol. Soc., London, IV; Amer. Journ. Sci., XLVI, 1844, 314–317; London Athenæum, 1842, No. 750; 1843, No. 796.

[2] Travels in North America, Vol. II, 90.

Bakewell[1] explained the St. David's channel as a valley excavated by water, then submerged and drift-filled. The present Niagara, in its gorge-cutting, has encountered this valley and excavated it rapidly, carving out a deep pit at the Whirlpool.

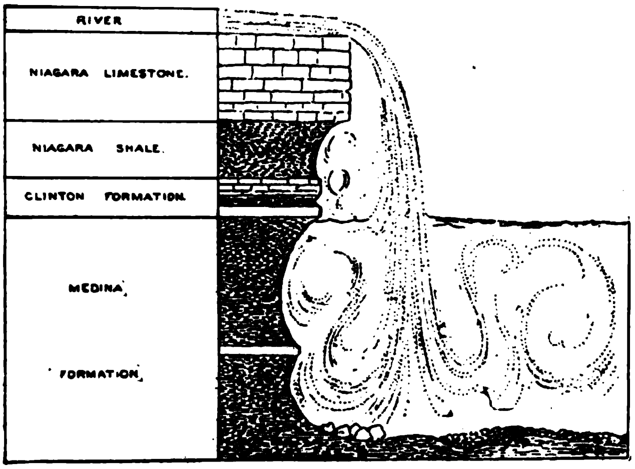

FIG. 154. Niagara limestone.

Agassiz[2] and Desor[3] wrote upon the Falls; and Gibbes,[4] opposing Desor, advocated Hall's view of the origin of the gorge, stating that the slow rate of retreat at the American Fall does not properly serve as a basis for argument upon the question of *general* retreat, since at one time there was no American Fall. We now know that Gibbes was right, for the American Fall is retreating very much more slowly than the Horseshoe Fall. Hall,[5] commenting upon Gibbes' paper, agrees with him, and states that, at the present rate of difference in retreat, the Horseshoe Fall will in time entirely rob the weaker American Fall.

Bakewell[6] in 1857, wrote once more upon the subject and stated that there had been a marked change in the

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[1] Amer. Journ. Sci., LIV, 1847, 25–36.
[2] Lake Superior, Boston, 1850, 15–16.
[3] Zeit. Geol. Gesell., V, 1853, 643–644.
[4] Proc. Amer. Assoc. Adv. Sci., X, Part 2, 1856, 69–76.
[5] Proc. Amer. Assoc. Adv. Sci., X, Part 2, 1856, 76–78.
[6] Amer. Journ. Sci., LXXIII, 1857, 85–95.

Falls since he first visited the region in 1829. He clearly stated the difference between the American and Horseshoe Falls in amount of work,[1] a difference earlier proposed by Gibbes, and argued that there is an immense pot-hole at the base of the Horseshoe Fall in which the fallen rocks of Niagara limestone are ground up, while the smaller volume at the American Fall is unable to dispose of the fallen boulders, which therefore remain as a protection to the weaker rocks underneath the limestone.

The river gravels of Goat Island were mentioned by Ramsay;[2] and the Falls were described in popular articles by Hyatt[3] and Tyndall.[4] Holley criticised the latter and stated certain facts observed by him which led him to the belief that the rate of retreat of the Falls is about 4 inches a year, making the age of the gorge 72,000.[5] Belt also wrote a popular article.[6]

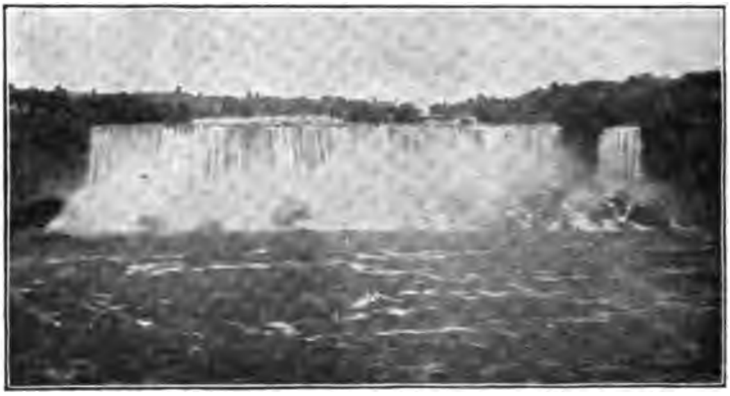

Fig. 155. The American Fall, showing the large boulders which encumber its base because the cataract has not power enough to remove them as they fall.

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[1] See also, upon this point and others connected with Niagara, Marcou, Bull. Soc. Geol., France, 2d Ser., XXII, 290–300, one of the important early studies.

[2] Quart. Journ. Geol. Soc., XV, 1859, 212–215.

[3] American Naturalist, II, 1868, 77–85

[4] Popular Sci. Monthly, III, 1873, 210–226; Macmillan Mag., XXVIII, 1873, 49–62.

[5] Holley, Proc. Amer. Assoc. Adv. Sci., XXII, 1873, 147–155. See also Holley's Falls of Niagara, New York, 1883; Niagara, its History, Geology, etc., 12th ed., Toronto, 1872. See also Gunning, Popular Science Monthly, I, 1872, 564–573.

[6] Quart. Journ. Sci., XII, 1875, 135–136; see also Carpenter, Nature, XXIII, 1881 511–514.

SUMMARY OF RESULTS OF EARLY STUDIES.—As a result of these studies, it may be stated that, while there was still much that was purely speculative, many of the major problems of Niagara were solved by them. It was proved beyond question, for instance, that a large part, and probably all, of the gorge had been cut out by the action of the river water. A number of persons contributed to this proof, the last important one being Lyell. Although estimates varied, a fairly close approximation to the rate of present retreat had been made, and the age of the gorge had been stated in figures, though in nearly every case with a clear recognition of the fact that there were causes which had operated to modify any estimate based upon the present rate.

The existence and significance of the Whirlpool-St. David's channel had been discovered, and the relation of the Whirlpool to this gorge noted. The rapidity of retreat of the Horseshoe Fall had been clearly recognized and the difference between it and the American Fall pointed out. It was also shown that, at the present rate, it was merely a question of time when the Canadian Fall would rob the American of its water and the two falls be replaced by one, which in time would change to a series of rapids, when, with the southward dip of the strata, the underlying shale had dipped down so far that the swirl of the cataract water could not reach it and remove it from beneath the Niagara limestone.

Many other facts had been stated and many logical conclusions had been drawn fully a quarter of a century ago. Indeed so much had been learned that it would have seemed as if little more were left to be done. But the publication of discussions has continued down to the very present, and it should be said that, as a result of these, we are now less certain of some things connected with Niagara than we were in 1880. It is chiefly as the result of the later studies of the Great Lakes that new facts have been discovered which apply to Niagara. This is particularly true of that part of the Niagara problem which relates to the *age* of its valley. For a while the gorge seemed to promise to serve as a geological chronometer ot great importance; and from very early times this aspect of the Niagara problem has received marked attention. In later years this part of the question has been analyzed more carefully; and, because of its importance, we will now take it up specifically.

Present Rate of Retreat.—In the first three-quarters of this century any estimate of the existing rate of retreat of Niagara Falls was necessarily based upon very meager evidence and amounted to little more than a guess, as is shown by the wide variety of opinion expressed. By the wise foresight of Dr. James Hall,[1] the State Geologist of New York, a map based upon an instrumental survey was made in 1842. In 1875 the Lake Survey, under the direction of Major C. B. Comstock of the Corps of Engineers of the U. S. Army, prepared its map of the Falls and gorge (Fig. 143). Wright made use of these maps[2] to make

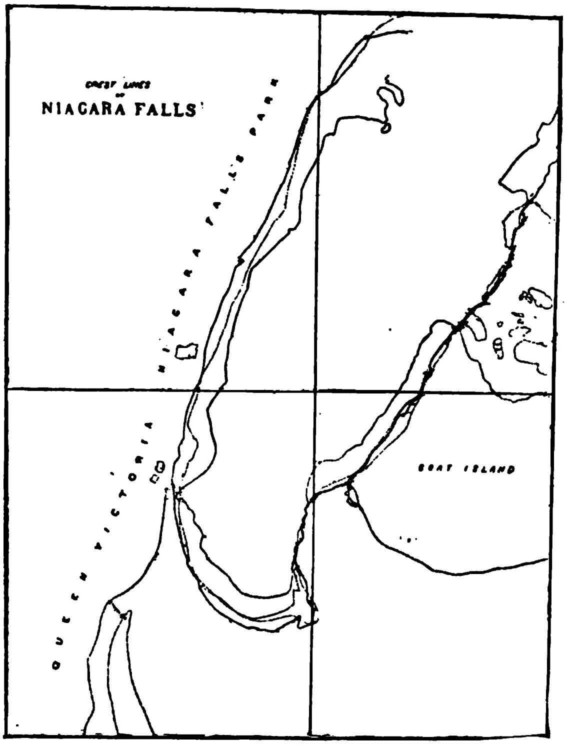

Fig. 156. Crest lines of Niagara Falls (after Kibbe); outer (upper) line, survey of 1842; second line, survey of 1875; third line, survey of 1886; fourth line, survey of 1890.

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[1] Geol. of New York, 4th Dist., 1843, 402.

[2] Science, V, 1885, 399-401.

an estimate of the rate of retreat, from which he placed the age of the gorge at about 7,000 years, though he mentioned the fact that there are elements of uncertainty in such a calculation because of probable variations from this rate. Wesson[1] gave the rate of retreat of the American Fall as 10 inches, and the Horseshoe Fall 3½ feet a year. This makes about 10,000 years as the age of the gorge, assuming a constant rate for the past.

A survey by Woodward in 1886[2] served Gilbert[3] with an opportunity of stating that the rate of recession in the central third of the Horseshoe Fall for 44 years was about 200 feet. With the same rate the age of the gorge must be calculated at about 7,000 years; but he points out many possible variables. Another survey was made in 1890,[4] by which it is shown that the average annual retreat in 48 years is .64 feet for the American Fall and 2.18 feet for the Horseshoe; but the rate of retreat in the central part of the Horseshoe Fall is much faster, and from this the rate of gorge formation is to be calculated.

CAUSES FOR PAST VARIATION IN RATE.—Gilbert has given the clearest and most complete statement for past variation in rate of gorge cutting,[5] as he has, in fact, upon the general question of Niagara River. He notes the following causes:—possible presence of preglacial or interglacial valleys coinciding with a part of the present valley, thus increasing the rate; a thinner limestone and a greater thickness of the under shales in the lower course, together with a former greater height of the fall, all of which tend to increase the rate; a narrower channel in places, which has called for less work; the probable presence of floating ice to help in the excavation; and, finally, possible variations in detrital load, in the chemical composition of the water and in its *volume*.

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[1] Nature, XXXIII, 1885, 229-39. See also a brief note by Garbett in same, 244-245.

[2] Science, VIII, 1886, 205.

[3] Proc. Amer. Assoc. Adv. Sci., XXXV, 1886, 222-3; Science, VIII, 1886, 205; See also Gilbert, Nature, L, 1894, 53; also Kingsmill, same, 338.

[4] Kibbe, Seventh Rept. Niag. Reserve Comm., 1891, 96-102; Woodward, 103-116.

[5] Proc. Amer. Assoc. Adv. Sci., XXXV, 1886, 222-3; Science, VIII, 1886, 205.

The latter point has been elaborated by Spencer[1] and by others. Spencer has shown that when the land was lower in the north[2] the waters of the Great Lakes were diverted from Niagara, which then contained only a small stream. He believes that the early Falls were somewhat like the present, and that these were followed by three falls, as at present in the Genesee. The life of the river is divided into episodes, each of which is estimated, making the total life of the river 32,000 years and of the gorge 31,000 years.

FIG. 157. The Rapids above the Falls.

The view of the variation in volume of water previously suggested by Gilbert, and definitely advanced by Spencer, is accepted by Gilbert in later articles.[3] But it is to

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[1] Proc. Amer. Assoc. Adv. Sci., XXXVII, 1888, 197-199; Trans. Roy. Soc. Canada, VII, Sect. IV, 1889, 121-134; Proc. Amer. Assoc. Adv. Sci, XLIII, 1894, 244-246; Amer. Journ. Sci. CXLVIII, 1894, 455-472; Amer. Nat., XXVIII, 1894, 859; Amer. Geol., XIV, 1894. 298-301; Proc. Roy. Soc., LVI, 1894, 145-148; Pop. Sci. Monthly, XLIX, 1896, 157-172; Amer. Geol., XXI, 1898, 110-123; Amer. Journ. Sci. CLVI, 1898, 439-450. A number of Spencer's papers are reprinted in Eleventh Rept. Niagara Comm., 1895, App., 1-126. For references to other papers by Spencer see Chapter VIII, p. 245.

[2] Spencer, Amer. Journ. Sci. CXLVIII, 1894, 455-472.

[3] Sixth Rept. Niagara Comm., 1890, 61-84; same Rept. Internat. Cong. Geol. 5th Session, Washington, 1891 (Pub. 1893), 455-458; Physiography of United States, New York, 1896, 203-236.

Taylor that we owe the latest and most thorough study of the ancient outflows of the Great Lakes, by which Niagara has been temporarily robbed of its water (pp. 259–265); and he has naturally made application of these studies to the Niagara problem.[1]

Taylor's conclusions concerning the influence of variation in water supply on the age of the Niagara gorge may be briefly summarized as follows: In the first place, he shows how variable are the width and depth of the gorge in different parts. There is first an *upper great gorge* extending from the base of the Falls nearly to the railway bridges, being broad and deep. This is followed by the second section of the gorge, the *Whirlpool Rapids*, shallow and narrow, and this by the third section, the *middle great gorge*, which includes the Whirlpool and extends below it.

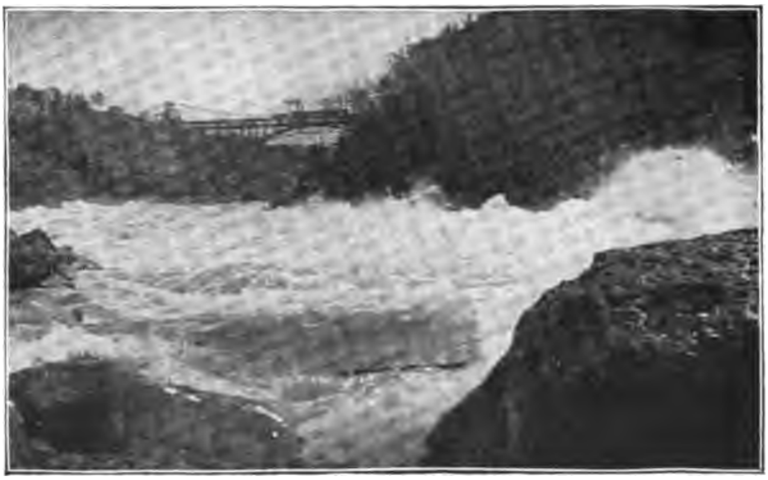

FIG. 158. The Whirlpool Rapids.

Here the width is about that of the upper great gorge and the depth is considerable. This is followed by the fourth section, the *lower gorge*, which is prevailingly narrow and rather shallow, for the most part.

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[1] Taylor, Amer. Journ. Sci. CXLIX, 69–71; 249–270; Amer. Geol., XV, 1895, 100–120; 162–179; Amer. Geol., XVIII, 1896, 108–120; Amer. Journ. Sci. CLIII, 1897, 208–218; Studies in Indiana Geography, Terre Haute, 1897, 109–110; Amer. Geol. XX, 1897, 65–66; 111–128; Proc. Amer. Assoc. Adv. Sci. XLVI, 1897, 201–202; Bull. Geol. Soc. Amer., IX, 1898, 59–84. See particularly last paper.

Taylor thinks that the upper broad gorge may be the part that has been formed since the Nipissing outflow was abandoned; and, at the present rate of cutting, this portion of the gorge has required about 2,700 years. The Whirlpool Rapids section he believes to have been formed by the river when it was so small that the Niagara limestone boulders were not removed, the fall at that time being similar to the present American Fall in mode of work. At this rate of cutting, the Whirlpool Rapids section must have required several thousand years, the amount not being definitely estimated by Taylor. The reason for the small volume of Niagara at this period was the withdrawal of the waters of the upper Great Lakes across Nipissing Pass (p. 263). The broad section below this is supposed to have been formed when the volume of Niagara was large, just before the time of the Nipissing overflow.

No attempt is made to analyze the paper and to state the facts which Taylor brings forward in support of this hypothesis. Without a very much longer abstract than is possible here, justice could not be done to the paper, and it is necessary to refer to the publication itself, if the reader wishes to follow Taylor's argument in detail. It is an exceedingly brilliant piece of work, and calls for very careful consideration on the part of students of the Niagara problem.

The outflow over the Nipissing Pass, through which the waters of the Great Lakes passed to rob Niagara of its volume, has also been studied by Wright;[1] but he does not agree with Taylor in the assumption of long overflow over this Pass, upon which Taylor bases much of his argument for the great age of Niagara gorge.[2] Upham[3] has taken a vigorous stand against the long occupancy of this overflow of the Great Lakes, as maintained by Taylor. So it will be seen that the somewhat startling conclusion reached by Taylor, that the Niagara gorge is not less than 30,000–50,000 years old, is based upon an interpretation of the facts to which all do not agree.

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[1] Bull. Geol. Soc. Amer. IV, 1893, 423–425. See Bell's comment on this, pages 425–427.

[2] Amer. Geol., XXII, 1898, 260–261; Science, VIII, 1898, 502.

[3] 22d Rept. Minnesota Geol. Survey, 1894, 54–66; Nature, L, 1894, 198–199; Amer. Geol., XIV, 1894, 62–65 (Spencer's reply to this 135–136); 23d Rept. Minn. Survey, 1895, 156–193; Bull. Geol. Soc. Amer., VI, 1895, 21–27; Amer. Journ. Sci. CXLIX, 1895, 1–18; Amer. Geol., XVIII, 1896, 169–177; Amer. Geol. XXVIII, 1901, 235–244.

Another possible cause for the variation in rate of excavation of the Niagara gorge is the drift-filled St. David's-Whirlpool channel, first discovered by Lyell and Hall. This valley seems to represent a broad gorge cut into the rock to a level below the present water surface of the Niagara River at the Whirlpool. At what period this gorge was formed is not certain; but its time of development was evidently before the last advance of the glacier which clogged it with drift. Some ascribe it to interglacial, some to preglacial stream cutting (p. 163); but so far as the Niagara problem is concerned, the exact *origin* of the gorge is of little importance.

The question immediately concerning us is how far this gorge reached. Pohlman[1] believes that it represents the down-stream extension of the ancient Tonawanda Creek and that the gorge portion of this stream, now partly buried, really extended up the course of the Niagara as far as the railway bridges. Joining this, according to Pohlman, was a tributary from the northeast, also along the present course of the Niagara, having its source below the Whirlpool. The post-glacial Niagara encountered these interglacial or preglacial gorges, and quickly cleared them out, so that a very large portion of the present gorge was formed before the present Niagara was born, and was cleared of its drift-filling much more rapidly than the present rate of retreat of the Horseshoe Fall. According to Pohlman's argument, the age of the Niagara gorge, that is the length of the post-glacial time, is about 3,000 years.

No one appears to have accepted Pohlman's argument in full, though some have followed it in part. Spencer[1] argues against the theory that the gorge extended up stream, as Pohlman suggested. Indeed, in his later papers[2] he accepts the evidence presented by Claypole, and concludes[3] that there is rock extending across the supposed preglacial gorge, and hence that it was not a continuous stream course from the Whirlpool to St. David's, but a tributary to preglacial Tonawanda Creek. Gilbert,[4] however, says that the St. David's-Whirlpool gorge is a well-defined, filled channel, and not rock interrupted. He thinks that it extended up the present course of Niagara for a distance of 200 or 300 yards, and perhaps even further than this. Wright[5] believes that the buried gorge was made by a small preglacial stream, and that the age of Niagara gorge is from 10,000 to 12,000 years. Upham[6] suggests that the buried gorge extended up stream along the present course of the Niagara, and explains the narrowness of the Whirlpool Rapids section on this basis. He estimates the age of the gorge at from 5,000 to 10,000 years. A very different conclusion is reached by Taylor,[7] who ascribes the buried gorge to the action of a cataract that had just reached to the southern side of the Whirlpool basin when the glacier advanced to stop its work.[8] His estimate of the age is 50,000 years, or perhaps less.

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[1] Proc. Amer. Assoc. Adv. Sci. XXXII, 1883, 202; same, XXXV, 1886, 221–222; Trans. Amer. Inst. Mining Eng., XVII, 1889, 322–338. See also Upham, Amer. Geol. XXVIII, 1901, 235–244.

From this maze of conflicting estimates, it is impossible at present to reach a definite conclusion. The best I can do is to state what seems to me to be the present status of the problem of the post-glacial history of the gorge.

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[1] Amer. Nat.. XXI, 1887, 269–270.

[2] Spencer, Proc. Amer. Assoc. Adv. Sci. XLIII, 1894, 244–246; Amer. Journ. Sci. CXLVIII, 1894, 455–472; Amer. Geol., XIV, 1894, 298–301.

[3] Science, VIII, 1886, 246. See papers by Scovell announcing the discovery of a buried channel near Niagara, Amer. Geol., III, 1889, 195–196; Proc. Amer. Assoc. Adv. Sci. XXXIX, 1890, 245–246.

[4] Amer. Geol., XVIII, 1896, 232.

[5] Amer. Journ. Sci. CXXVIII, 1884, 32–35.

[6] Bull. Geol. Soc. Amer., IX, 1898, 101–110. See also Amer. Geol. XXVIII, 1901, 235–244.

[7] Bull. Geol. Soc. Amer., IX, 1898, 56–84.

[8] See also Davis, Amer. Journ. Sci. CXXXII, 1886, 323; also Davis, Johnson's Cyclopedia, 1895, article on Niagara, Consideration of the Problem.

In the early post-glacial stages of the river, its course extended five miles beyond the present mouth, as shown by Gilbert.[1] This gave to the river a lower base-level than that of the present, so that it was enabled to cut a deeper channel than was later possible.[2] At first the fall was not vertical, being made over the north-sloping escarpment; but it speedily changed, probably to a series of three falls, as argued by Hall (p. 279), or possibly to a torrential rapid, dependent upon the thinness of the Niagara limestone at the lower end of the gorge. Above Foster Flats, as suggested by Pohlman, the river may have encountered a buried tributary to the St. David's-Whirlpool gorge; or the drift-filled valley may not have been reached until the river had cut back to the northern edge of the Whirlpool. At whichever place this buried valley was first encountered, the fall abruptly changed to a rapid stream, which quickly cleared out the buried gorge as far as it extended, and then assumed the form of the present cataract. During this time the volume of water changed as the outflow of the upper Great Lakes varied in position, as has been stated by Gilbert, Spencer, Wright and Taylor.[3]

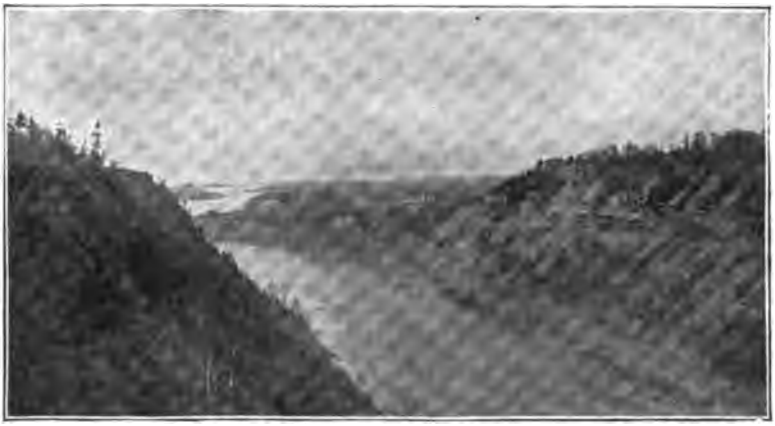

FIG. 159. The end of the Niagara gorge and the lower plain.

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[1] Sixth Rept. Niagara Comm., 1890, 61-84.

[2] Upham, Bull. Geol. Soc. Amer., IX, 1898, 101-110.

[3] See references (pages 244-265).

The ingenious argument formulated by Taylor,[1] correlating the narrow and broad parts of the gorge with the variations in water volume, has many facts in its support; but it must certainly be held for the present as no more than an alternative view of the Niagara gorge history. I feel by no means certain that his conclusions are necessary. The narrowness and shallowness of the Whirlpool Rapids section of Niagara may be easily explained by Pohlman's theory. If the St. David's-Whirlpool gorge was formed by a stream of moderate size, its width would not have been great, especially near the head of the gorge; and with the small volume of water available, the nature of the work done by the preglacial fall would have been rather like that of the present American than the Horseshoe Fall. The gorge bed would then have been littered with massive limestone boulders, as the bed of the Whirlpool Rapids evidently is at present. Above this section, that is from the railway bridges to the present cataract, the work, having been done by a great volume of water acting as the present Horseshoe Fall does, would be represented by a great depth of cutting.

From all the facts that have been put forward, it would be at least as reasonable to explain the Whirlpool Rapids channel in this way as by Taylor's explanation,—namely, by a contracted Niagara during the time when the upper Great Lakes were flowing through another channel. The ledge of sandstone rock mentioned by Taylor as existing just above the Whirlpool, on which he bases a part of his argument, may well represent a waterfall, over which the water of the preglacial or interglacial river flowed, as has been suggested by Pohlman.[2] It has been said that this explanation is at least as satisfactory as Taylor's; it may be claimed that it is somewhat more satisfactory, since it tells why the Niagara River turns sharply at right angles at the Whirlpool.

With regard to the variation in the width and depth of the lower gorge, it is more difficult to find an alternate explanation to that proposed by Taylor. It seems possible, however, that preglacial stream valleys, together with variation in the mode of work of Niagara, might explain this variation. What effect the change from a section of rapids to a series of three falls, and then to a cataract, might have upon the width and depth of the river valley, is not yet well enough known to warrant overlooking this as a possible explanation of the variation. Taylor's explanation is certainly a remarkable one, especially with respect to the close coincidence of alternations of broad and narrow gorges with the known alternations of large and small volume of water.

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[1] Bull. Geol. Soc. Amer., IX, 1898, 56–84; see also page 287 of this book.

[2] Proc. Amer. Assoc Adv. Sci., XXXV, 1886, 221–222; Trans. Amer. Inst. Mining Engineers, XVII, 1889, 322–338.

While the discussion by Taylor is a brilliant one and has many points in its favor, I find myself unable to accept his conclusions, partly because they do not seem necessary, and partly because they lead to a startling conclusion, which is quite at variance with other evidence.

In the first place, if the age of Niagara gorge is from 30,000 to 50,000 years, as the studies of Taylor and Spencer seem to indicate, the lower end of the gorge is from 30,000 to 50,000 years older than the upper. Yet no very noticeable difference in effect of weathering on the two ends can be found.[1] It would seem that such a long time must have permitted considerable effect of weathering, especially as the rate in recent years is known to have been noticeable in the lower part of the gorge near the railway line.

Moreover, before Niagara was born, beaches, terraces, eskers and drumlins were laid down as the direct or indirect result of the presence of the glacier, and these are now so fresh and undestroyed that from all the evidence they present they might be no more than 1,000 years old. Tiny stream channels on deltas are still preserved, and many other delicate forms of sculpturing testify to the youth of the deposits. If 30,000 years of exposure to denudation is not sufficient to noticeably modify such delicate land forms, surely geologists must call for vastly greater periods of time than they are in the habit of calling for to account for the planing down of mountains over and over again. Such a conclusion as that of Taylor seems quite out of harmony with what we are accustomed to believe concerning the rate of denudation. It would, of course, have to be accepted, if actually proved; but so long as it is an hypothesis, only partially supported, one is justified in hesitating to accept it when another explanation seems equally good, or better, and does not lead to so great and apparently improbable an age for the gorge.

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[1] Wright, Science, VIII, 1898, 502; Amer. Geol., XXII, 1898, 260–61; Proc. Amer. Assoc. Adv. Sci., XLVII, 1898, 299–300; Popular Sci. Monthly, LV, 1899, 145–154. See also Wright, Bull. Essex Inst., XIII, 1881, 71; Upham, Bull. Geol. Soc. Amer. IX, 1898, 101–110.

It has been pointed out by Hansen[1] that thirty independent estimates of post-glacial time, based upon different data, give results of between 5,000 and 12,000 years,[2] so that on the basis of probability the age of Niagara gorge should be somewhere between 7,000 and 10,000 years.

Gilbert says[3] that the problem of the age of Niagara cannot "be solved by a few figures on a slate, nor yet by the writing of many essays." To this every one who has given attention to the problem must assent. The longer the study, the more complex the problem appears, and we are bound to conclude that Niagara is not a good chronometer. Until more evidence has been obtained concerning the length of the overflow at Nipissing Pass, which some believe to have been long, others short, we may have to remain in doubt whether the age is from 5,000 to 10,000 years or from 30,000 to 50,000 years.

The present rate is fairly well known; the former rate was less, for a time, when the volume of water was diminished; but the question of how long this diminution lasted cannot be answered with positiveness. While this factor would lengthen the time to an amount which cannot be definitely stated, it is worth while to note that nearly all the other important factors for variation would tend to shorten it by increasing the rate of river work. Among these factors the more important ones are as follows: We know that the limestone in the lower part of the gorge is thinner than at the present cataract, and it seems certain that, as a result of this, the rate of cutting was once greater. At that time the height of the fall was greater and the shales beneath were thicker and hence more easily removed. At the same time it is to be noted that the mode of gorge formation was then different from the present, for at first there were probably three falls instead of a single one. In places the gorge is narrower than the one at present forming, so that less material had to be removed. Moreover, it seems certain that a part, and possibly a considerable part, of the present gorge was excavated before the *present* Niagara began its work.

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[1] Journ. of Geol., II, 1894, 142.

[2] Upon this subject, see Winchell's discussion of St. Anthony Falls, Fifth Annual Rept. Minnesota Geological Survey, 156–189; Quart. Journ. Geol. Soc., XXXIV, 1878, 876–901; Final Rept. Minnesota Survey, Vol. II, 1888, 313–341.

[3] Sixth Annual Rept. Niagara Comm., 1890, 83.

When the ice sheet was withdrawn there must for a while have been a heavier rainfall, because of the neighborhood of the cold ice wall, which chilled the damp air from the south, doubtless rendered more damp than now because of the large amount of water near the front of and flowing away from the glacier. This rainfall must then have flowed off more freely and carried with it more sediment than at present, because, when the ice first withdrew, there was no forest cover to the land and at first no coating of vegetation whatsoever. There is evidence in many of the gorges of the Finger Lakes of central New York that this was so, and that the rate of work done in the early stages of the gorge formation was very much greater than it has been since the streams became diminished to their present volume. In these stream valleys there are usually two gorges, one broad, the other, inner one, narrow.

While it is certain that we must keep in mind the argument brought forward by Taylor and hold it as a working hypothesis, we must admit that the Niagara problem is by no means solved. My own interpretation of the evidence, as it at present stands, is that the indications are rather more strongly in favor of the theory that the gorge has required less than 10,000 years for its formation than toward the estimate of 30,000 to 50,000 years. The basis for the latter is too uncertain for its acceptance at present, particularly in the face of the difficulties which it brings forward. There is work yet to be done on the Niagara problem.

FOSTER FLATS.[1]—The rather remarkable projection of the side of the gorge at Foster Flats, just below the Whirlpool on the Canadian side, is worthy of special study. At this point is a projecting platform of Niagara limestone forming the land known as Wintergreen Flat. This represents an old river bed swept clear of drift by the current. Between this water-swept limestone platform and the electric car track there is a bluff of drift which represents one of the old river banks.

FIG. 160. The Niagara gorge.

Standing on the northern edge of this platform one sees at his feet, at the base of a precipitous wall, a north-sloping valley littered with huge blocks of Niagara limestone, and bounded on the west, or left, by the normal gorge wall, on the right by a low ridge, strewn with loose blocks of the limestone.

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[1] Gilbert, Physiography of the United States, New York, 1896, 220.

Gilbert's explanation of these facts is that, at this point there existed, in the course of the Niagara, a small island which separated the cataract into two unequal parts, much as the larger Goat Island now divides the Falls, though with this exception,—that the Canadian Fall was then the smaller. The larger American Fall of these ancient times naturally retreated more rapidly than the smaller Canadian, and soon caused a withdrawal of the water from the Canadian side. This smaller fall had swept clear the channel and rock platform just described, and existed as a fall somewhat like the present American Fall. For a while after this stage the small Canadian cataract fell eastward over the edge of Wintergreen Flat, and then the larger fall on the American side entirely robbed it of its water. The ancient Canadian Fall, like the present American, having been unable to remove the boulders from its foot by grinding them together, has left them there as one of the silent witnesses of the former existence of the falls. The narrow island, which was responsible for the division of the river, was so small that it was not able to withstand the later attacks of the water and weather and has almost entirely disappeared, being marked at present only by a low ridge which separates the present river from the abandoned channel. This region of Wintergreen and Foster Flats is one of the most interesting in the whole course of Niagara River and well worth a visit by tourists, not alone for its scientific interest, but also because of its scenic beauty. Notwithstanding this, not one in five hundred visitors stop off to see it.

FUTURE OF NIAGARA.[1]—Already the question of the rapid change in the present form of Niagara Falls has been briefly considered. Upon the assumption that the conditions at present in existence are to continue, it seems evident that in time the American Fall will be robbed by the Canadian, and that there will come to be another dry platform where now the water rushes to the brink of the smaller fall. Moreover, when the cataract retreats up stream and reaches a region where the limestone becomes much thicker, its *rate* of retreat will decrease; and, finally, when the shales have dipped far enough into the earth to have practically disappeared from the reach of the water, the cataract will probably change to a series of rapids, and Niagara Falls will of course disappear.

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[1] See Hallett, Geol. Mag., Decade III, 1, 563-564.

But there may be some interference with this normal future. Leaving out of the question what man may do, it is by no means impossible that the water of Niagara may be entirely withdrawn from the present river. There is evidence enough that the level of the land is very unstable, and that this very instability has previously caused the withdrawal of the water from the Niagara channel by opening lower outlets for the Great Lakes.

Spencer[1] brings forward evidence that the region near the Niagara River has recently changed in level, and concludes that there is an uplift still in progress at the rate of about 1¼ feet a century. If this rate should continue in the future, as Spencer believes it has for the past 1,500 years, the Great Lakes will discharge into the Mississippi past Chicago in about 5,000 years from now. Gilbert[2] has more recently reached a similar conclusion. As the result of a very delicately made survey, he finds that there has apparently been a change in level during the time that has elapsed since certain bench marks were located near the shores of the Great Lakes. This recent change amounts to 6 inches a century at Duluth, 9 inches at Toledo, and 9 to 10 inches at Chicago. If this rate of uplift continues, the waters of the Great Lakes will begin to spill over the rim at Chicago in from 500 to 600 years from now, and in 3,500 years Niagara will be dry. To this prediction, however, one cannot attach any more weight than to the numerous estimates of the length of time occupied in the formation of the gorge. The future of Niagara, as well as its past, is wrapped in uncertainty.

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[1] Amer. Journ. Sci. CXLVII, 1894, 207-212; Proc. Amer. Assoc. Adv. Sci. XLIII, 1894, 243-246; Amer. Geol., XIV, 1894, 298-301; Amer. Journ. Sci. CLVIII, 1894, 455-472.

[2] Nat. Geog. Mag., VIII, 1897, 233-247; Eighteenth Annual Report U. S. Geol. Survey 595-647. See abstract of this in Bull. Amer. Geog. Soc., XXXI, 1899, 156.

NOTE.—It is not pretended that the bibliography in this paper is complete. A number of references (as to Belt, Bigsby, etc.,) which I have had, were in volumes not accessible to me; others were omitted to save space. A bibliography of Niagara, especially the popular accounts, will be found in the Tenth Report of the Niagara Commission, 1894, 72–107, and also in Eleventh Report, 75–84. See also the bibliography in Grabau's paper, Bull. New York State Museum, No. 45, 1891, 253–262. In most of the geological text-books, as those by Dana, Geikie, Le Conte, Winchell, and others, Niagara is at least mentioned. See also the earlier text-books, as Bakewell, Introduction to Geology; De la Beche, Geological Manual, and Lyell's Principles of Geology.

CHAPTER X

THE SHORE LINES[1]

NATURE OF THE COAST LINE.—As one looks at the map of New York, the first thought is that the coast line extends over a very small area; but strictly there is a rather extensive stretch of shore line, for not only must the entire boundary of Long Island be included (Figs. 174 and 176), together with the coast in the vicinity of New York, but the shores of the Hudson as far as the tide extends; that is about as far up as Troy. Then, also, there is the extended southern coast of Ontario, and a part of Erie, within the State boundaries, besides the shores of many other lakes, large and small.

It is fair to consider the lake and ocean shores together, since, broadly speaking, they are the same in kind and origin. On exposed coasts, as on the outer end of Long Island, the wave action is more powerful than it can be in any lake; but the lake waves in Ontario are more powerful than the ocean waves in protected parts of Long Island Sound; and in many of the small lakes of the State the power of the waves is as great as in the Hudson estuary. In *intensity*, therefore, the wave action in lakes resembles that in ocean bays; but even where the waves are more powerful, as on exposed ocean coasts, the results produced upon the shore lines differ from those in lakes and bays only in degree, and not in kind.

Besides the greater intensity of open ocean waves, there is also a difference between lakes and oceans in the tidal action of the latter. Tides and tidal currents are practically absent from small lakes, and hardly noticeable in the larger ones, such as Ontario;[1] but in the sea they are very effective agents of change. Another difference between lake and ocean coasts is the life, both plant and animal, which produces marked influence on certain shore lines. Otherwise these coasts are much alike, essentially the same changes being in progress, and the same general results being produced.

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[1] For general discussion of shore lines see Gilbert, Fifth Annual Report, U. S. Geological Survey, 1885, 69–123; Monograph I, U. S. Geological Survey, 1890, 23–89; Gulliver, Proc. Amer. Acad. Arts and Sciences, XXXIV, 1899, 151–258 (contains an excellent bibliography); Desor, Foster and Whitney, Lake Superior Report, Part II, 1851, 256–270.

EFFECT OF ELEVATION.—Given a sea shore standing at one level for a considerable time, let us examine the results. The waves would gnaw their way into the land, and the currents would deposit the debris off shore, naturally strewing it more or less regularly over the bottom. In time the result would be an off-shore submarine plain, composed of unconsolidated debris. Now, let us assume an uplift which raises a part of this sea-bottom plain into the air—such an uplift, for instance, as might extend the coast of New York and New Jersey forty miles further seaward. This would elevate into the air a level coastal plain traversed by some valleys and dotted with basins, in which water would soon gather; but the boundary line, where the sea and land meet, would form a rather straight coast line. The conditions at present illustrated on the Texas coast would in general be reproduced; and, as in the case of the Texas coast, the waves and currents would act upon the soft, unconsolidated clays and sands of the old sea-bottom plain.

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[1] The tides and other fluctuations in level of the Great Lakes, including the seiches, are described in the following papers; Dearborn, Amer. Journ. Sci. XVI, 1829, 78–94; Whiting, Amer. Journ. Sci. XX, 1831, 205–19; Sharpe, Phil. Mag., IX, 2d Ser. 1831, 117–19; Mather, Geol. Survey Ohio, 2d Annual Rept., 1838, 23–24; Whittlesey, same, 50–53; Dewey, Amer. Journ. Sci. XXXIII, 1838, 403–5; same, XXXVII, 1839, 242–3; Ruggles, Amer. Journ. Sci. XLV, 1843, 18–27; Hall, Fourth Dist. Geol. of New York, 1843, 408–410; Dewey, Amer. Journ. Sci. LII, 1846, 85–7; LIII, 1847, 444; Mather, Amer. Journ. Sci. LVI, 1848. 1–20; Foster, Proc. Amer. Acad. Arts and Sciences, II, 1848–52, 131–6; Foster and Whitney, Lake Superior Report, 1850, 47–53; Whittlesey, Foster and Whitney, Lake Superior Report, Part II, 1851, 319–339; Amer. Journ. Sci, LXII, 1851, 143–4; Lachlan, Amer. Journ. Sci. LXIX, 1855, 60–71; 164–175; LXX, 1855, 45–53 (from Canadian Journal, July, 1854); Whittlesey, Proc. Amer. Assoc. Adv. Sci., XI, 1857, 154–60; Whittlesey, Amer. Journ. Sci. LXXVII, 1859, 305–310; 447; Dewey, same, LXXVII, 1859, 398–399; LXXIX, 1860, 300–301; Graham, Proc. Amer. Assoc. Adv. Sci. XIV, 1860, 52–60; Whittlesey, Proc. Amer. Assoc. Adv. Sci. XXII, 1873, 42–6; same, XXIII, 1874, 139–143; Dawson, Nature, IX, 1874, 504–506; Schermerhorn, Amer. Journ. Sci. CXXXIII, 1887, 282–284; Drummond, Nature, XXXIX, 1889, 582; Drummond, Nature, XL, 1889, 416; Clark, Trans. Canad. Inst., II, 1890–91, 154–7: Harrington, Nature, XLIX, 1894, 592–3; Blunt, Annual Rept. Chief of Engineers U. S. Army, 1894, Part 6, 3431–35; Gilbert, Nat. Geog. Mag., VIII, 1897, 238–42.

No such condition as this is noticed in New York State at the present day; but at the time when the Hudson River reached seaward (p. 188) to the edge of the continental shelf, the contact of waves and land was at times of this nature; and, farther back in time when the great Paleozoic sea covered western New York, and the soft shales and sands of late Paleozoic age were being lifted out of the ocean by the Appalachian Mountain uplift, similar condition doubtless existed in a part of the State now far removed from the sea shore.

EFFECT OF DEPRESSION.[1]—Grant the same coast with which we started before, but this time assume the land to be depressed instead of the sea-bed to be elevated, and the conditions produced will be found to be very different. Streams have been flowing over this land, so that it has been carved into hills and valleys; and now, as the sea encroaches upon the sinking continent, it enters up the valleys, forming bays, while the hills between them form projecting headlands—capes if small, peninsulas if large (Fig. 161). With continued sinking, the sea reaches over cross valleys, forming islands with straits behind them; and, if the submergence proceeds still further, some of these lower hill-tops become entirely submerged, forming shoals.

Such a coast, in contrast with one due to elevation, is

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[1] The literature on submerged coasts is exceedingly extensive, and the following references are to only a few of those which describe the region included in this paper: De Geer, Amer. Geol., XI, 1893, 22–44; De Geer, Proc. Boston Soc. Nat. Hist., XXV, 1891–92, 454–477; De Geer, Amer. Geol., IX, 1892, 247–49; Upham, Bull. Geol. Soc. Amer., I, 1890, 563–67; Upham, Proc. Amer. Assoc. Adv. Sci., XLI, 1892, 171–3; Upham, Bull. Geol. Soc. Amer., III, 1892, 508–11; Cook, Geol. Survey New Jersey, Cape May Report, 1857, 15–65; Cook, Amer. Journ. Sci., LXXIV, 1857, 341–354; Cook, Annual Rept. Geol. Survey New Jersey, 1885, 57–70.

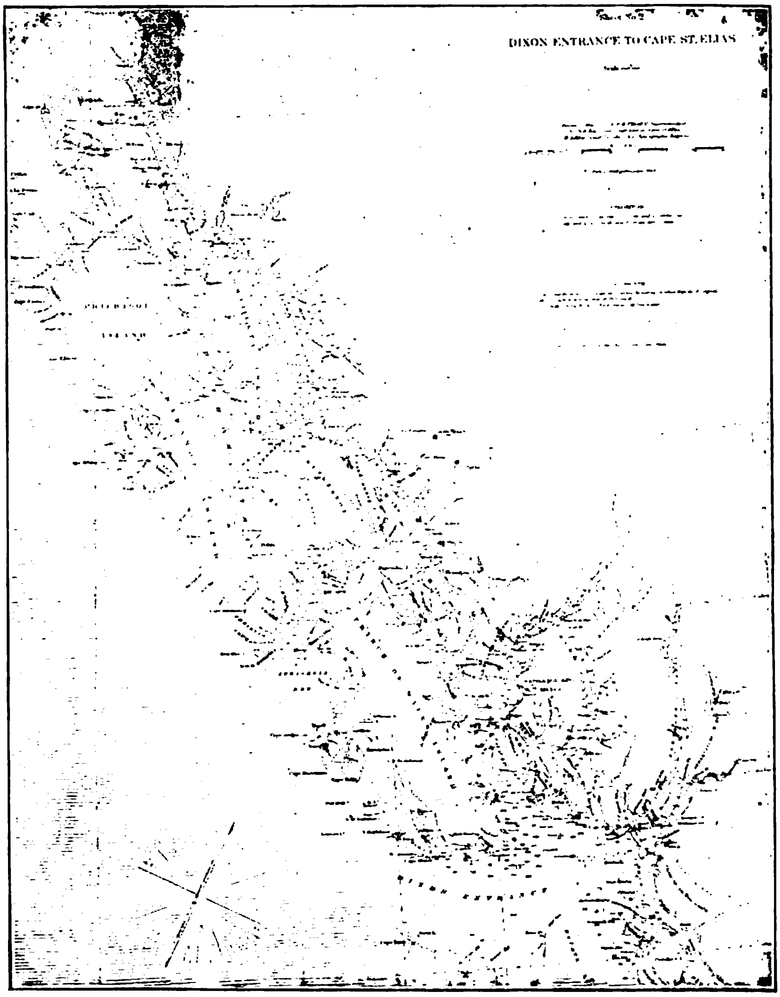

FIG. 161. A map of the drowned coast of a part of Alaska where the sea enters far into the land in numerous branching channels.

markedly irregular, the amount and nature of the irregularity varying with the amount of subsidence, the nature of the rocks, and the extent to which the land has been dissected by streams. Thus in the Canadian region, where the submergence has been extensive, and the hard rocks of the country were previously carved by the action of great rivers, not only have innumerable small bays, straits, capes and islands been produced, but also immense bays, like Hudson Bay and the Bay of St. Lawrence, immense peninsulas, like those of Labrador and Nova Scotia, large islands, such as Cape Breton Island, Newfoundland, etc., and extensive shoals,—completely submerged hills,—such as those forming the Fishing Banks. A similar subsidence has produced the irregular coast of the British Isles, and has severed them from the mainland by admitting the sea across the divide between two valleys, thus forming the English Channel.

In like manner the rocky coast of New England, with its innumerable islands and bays (Figs. 162 and 173), and the still more deeply indented fjord coast of Norway, tell of the entrance of the sea into a sculptured land of hard rock. On the other hand, the sinking of a land of softer strata, possessing a more subdued topography, produces a coast of irregular form, but of much less ruggedness. Such a coast is well illustrated in Chesapeake Bay and the other irregularities of the land-border south of New York.

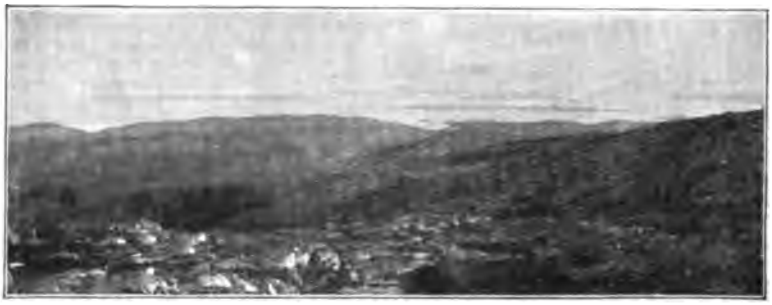

FIG. 162. A photograph from Mt. Desert, on the Maine coast, showing the numerous islands formed by the drowning of an irregular land area.

The depressed coast of the New York section stands midway between these two extremes, having some characteristics of each. Long Island Sound (Fig. 174) resembles the Chesapeake rather than the fjord type of depressed coast; but the Hudson, where it crosses the hard strata, is a true fjord of great length. The Bay of New York (Fig. 176), the islands near the city, including Long Island itself, and the narrow straits between these, are all the result of depression of the land. In fact, the site of New York City and its great possibilities as a seaport are due to this depression, first by forming a harbor, and secondly, by furnishing protected water communication, both eastward along Long Island Sound, and northward along the Hudson, and thence, by other means, westward.

This depression of the coast in the vicinity of New York City seems to be still in progress, both on Long Island and on the New Jersey coast. In the latter section various signs of subsidence have been discovered and discussed by the state geologist, the conclusion which he reached being that the present rate of sinking is about two feet a century.[1]

The formation of an irregular shore line may be produced in other ways, as by mountain folding or by volcanic action, both of which will cause islands, peninsulas, bays, etc., but neither of which is at present represented within the boundaries of New York. Another cause for irregularity of coast lines is illustrated in Lakes Ontario and Erie (p. 264). It has been shown that the land has recently risen in that section, with a greater uplift in the north than in the south. This has acted upon the water of the lakes of the State much as the tipping of a basin of water would act, that is, lowering the level of the water on one side and causing it to rise on the opposite side. The tilting of the land has caused an encroachment of the lake waters upon the southern shore, so that the lower valleys have in some cases been entered by the lake water and transformed to bays (Figs. 163, 181 and 182). An examination of a map of the State will furnish abundant illustrations of bays of this origin along the southern shore of Lake Ontario.

The valleys occupied by the lakes were of course formed before the lake water occupied them, often having been formed by stream erosion and transformed to basins by various causes, in New York State chiefly by drift dams

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[1] Cook, Geol. Survey New Jersey, Cape May Report, 1857, 15–65; Cook, Amer. Journ. Sci., LXXIV, 1857, 341–354; Cook, Annual Rept. Geol. Survey New Jersey, 1885, 57–70.

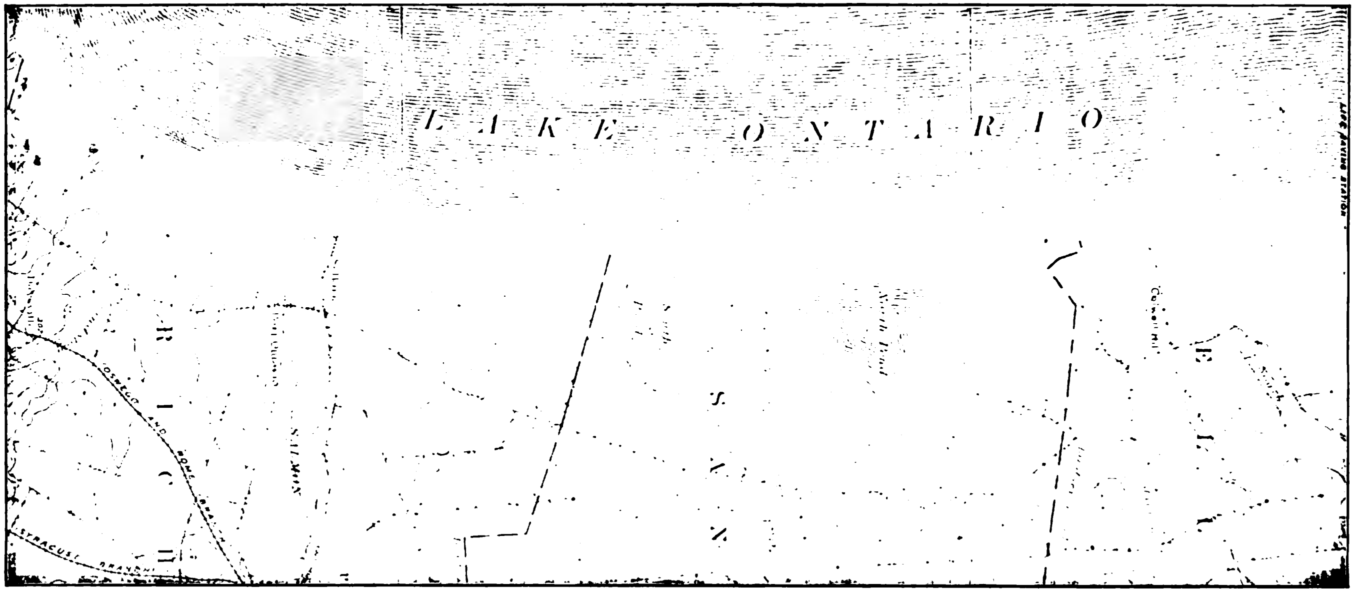

FIG. 163. A part of the southern shore of Lake Ontario where, because of tilting, the lake waters have entered the valleys, forming bays, now partly enclosed by the growth of bars across their entrances.

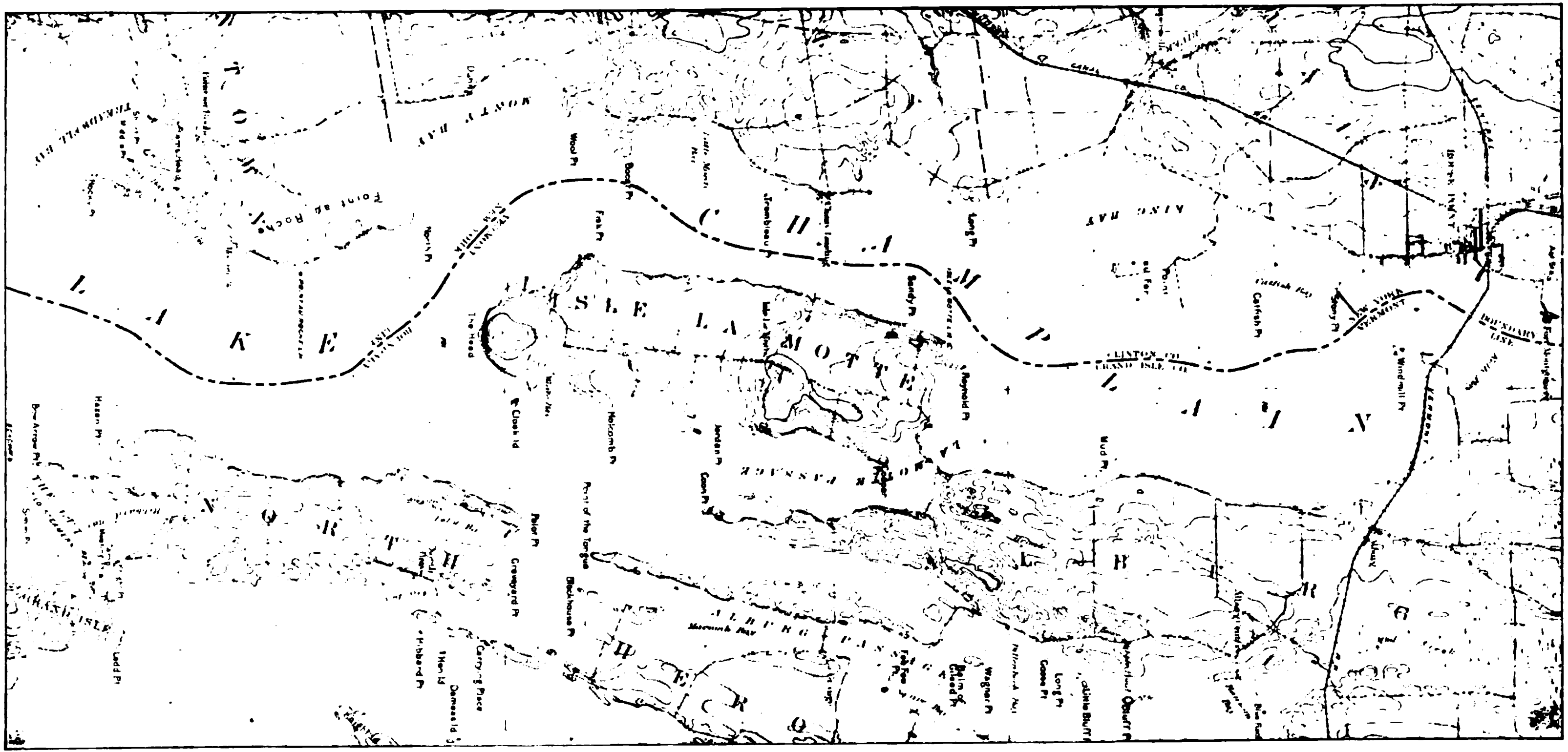

FIG. 164. A portion of Lake Champlain showing the very irregular coast due to the rise of the lake waters in a previously formed valley.

across some part of the stream valley. Many of the linear lakes of New York occupy parts of river valleys, as is especially well illustrated in the case of Lake Champlain (Fig. 164). When the dam for this lake was built and water ponded behind it, this naturally entered the side valleys, forming bays, capes, islands and straits, much as the sea water has formed them when the land has subsided. These irregularities, which are so well illustrated in the case of Champlain, are often in part due to the effect of tilting of the land, so that in any individual case it may be difficult to assign to each of these two causes its relative importance. The marked irregularity of the eastern end of Lake Ontario, including the Thousand Islands (Fig. 165), is due to the rise of the lake waters over pre-existing land

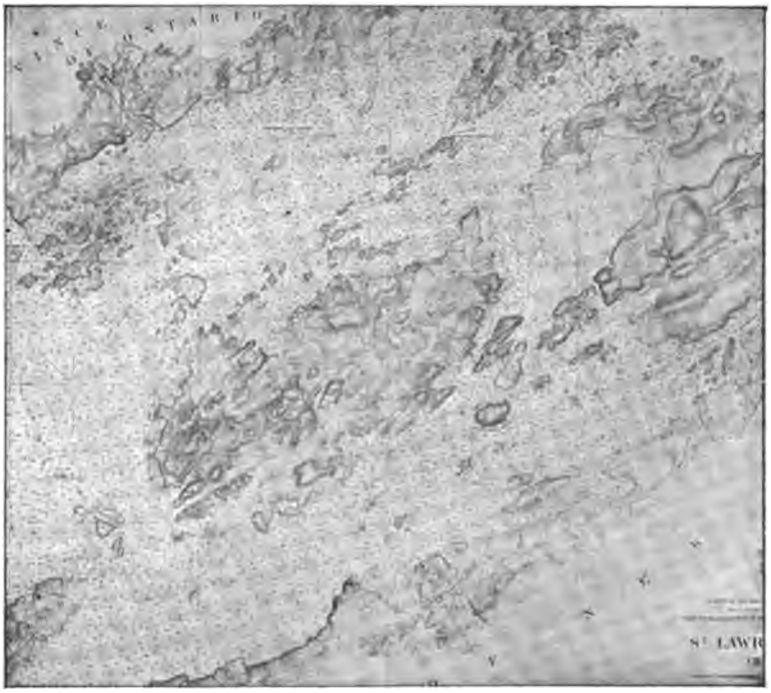

Fig. 165. Map of a portion of the Thousand Islands where the waters of Lake Ontario rise over a low, hilly land surface, submerging a part and transforming the higher portions into islands and peninsulas.

until they have overflowed across the irregular land area, in this case a low hilly divide; for the Thousand Island outlet is in no sense the preglacial course of a stream of large size.

DESTRUCTIONAL FORMS.— Having briefly considered the causes for the marked difference between coasts resulting from land movement, we will now proceed to the consideration of some of the minor changes to which a coast of either origin is subject.

Waves are the most potent of the aqueous forces which are working toward the modification of the coast lines. Beating incessantly against some parts of the shore, they find two tasks to perform—one to grind off fragments, the other to dispose of them. In places where the materials obtained by the waves, whether by their own action or supplied by other causes, can be removed, either by wave or current action, the shore line is attacked and cut back, producing certain forms which may be classed as destructional forms. The attack of the waves upon such a coast line varies in intensity primarily with the force of the waves and the hardness of the rock, being most rapid, other things being equal, where the rock is soft and the wave action vigorous.

Where the strata are soluble, as along limestone coasts, solution is a factor; and in many rocks the disintegration of the minerals is hastened by the salt of the spray and by other impurities from the sea water.

Aside from the action of solution, the waves are often able to wrest off fragments by their direct blow, as the result of the compression of air in cavities and the tremendous hydraulic pressure produced by the wave blows. By means of the materials obtained by this action, together with the supply furnished from the land by weathering, by wind and by rivers, the waves are supplied with effective tools, with which they can batter the rocks of the coast and wear them back. It is mainly by this mechanical work, rather than by solution, that the coasts are worn back into the land; and among the factors involved, the most important is the mechanical action of the waves armed with rock fragments.

The battering ram of wave action is concentrated along a moderately narrow plane, its width varying with the height of the waves; but even in this zone there is a still smaller belt of maximum wave attack, and along this belt the waves saw into the rocks with a rapidity which in many places is sufficient to be noticeable in a single lifetime. This zone of maximum wave action swings up and down with the tides, and this swing constitutes one of the differences between lake and sea shores; but even in lakes, the fluctuations in level due to seiches and other causes (p. 301) produce a certain swing in the zone of maximum wave attack.

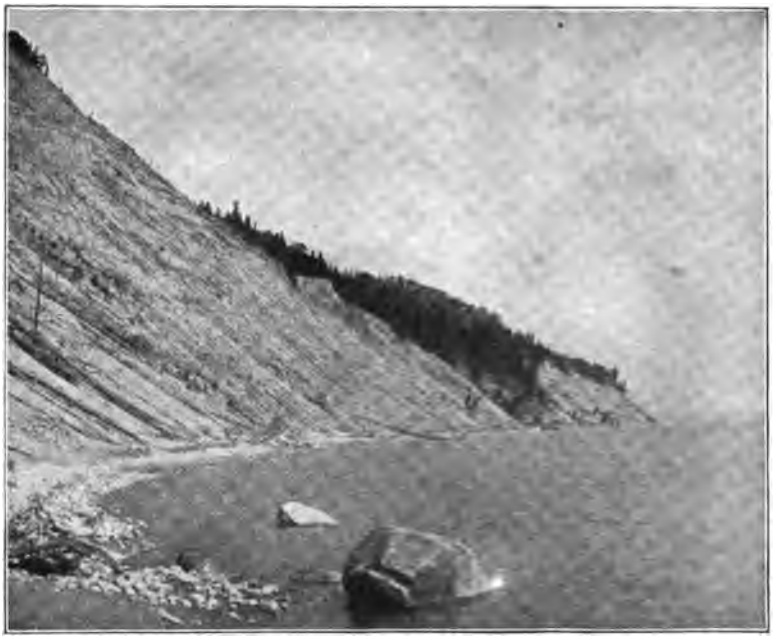

FIG. 166. A wave-cut cliff in unconsolidated strata on the shore of Lake Michigan. That this cliff is being cut back at the present time is proved by the absence of vegetation on its face and by the very narrow beach at its base.

Where the waves are eating into soft, unconsolidated strata, the removal of materials from the zone of wave

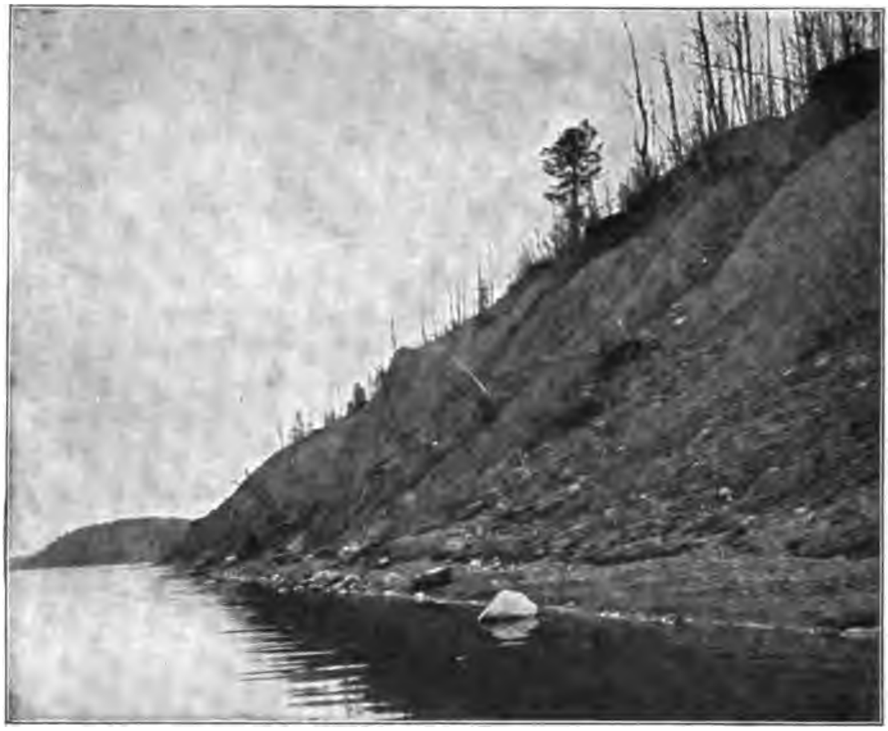

Fig. 167. A wave-cut cliff on the shores of Lake Ontario, east of North Fairhaven Bay. This is a drumlin that the waves are cutting back at a very rapid rate. (J. O. Martin, photographer.)

action undermines those layers that are above it, causing a succession of slides and slips, and producing a cliff with the slope which such materials naturally assume in the air (Figs. 166 and 167). With a continuation of these attacks such a cliff is cut further and further back into the land, always maintaining a steep slope, and in general, free from plant cover so long as the waves are able to remove the supply which they gain. From these bare slopes much rock material is washed into the water by the rain and rills, adding to the burden of the waves. Such wave-cut cliffs of clay, sand and gravel are frequently found along the shores of the Great Lakes and also in exposed places on the shores of the smaller lakes.

Much the same result occurs where the waves beat

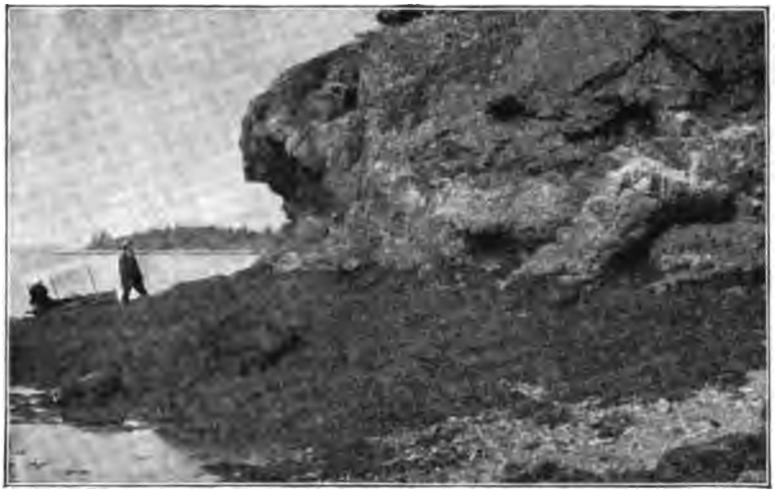

FIG. 168. A wave-cut rock cliff at Castine, Maine, overhanging above the zone of most active wave attack.

against hard rocks; but here the resistance of these more durable layers often permits the waves to undercut the cliffs, (Fig. 168) forming sea caves. More commonly, however, the rock cliffs are nearly vertical, with a slight inclination from

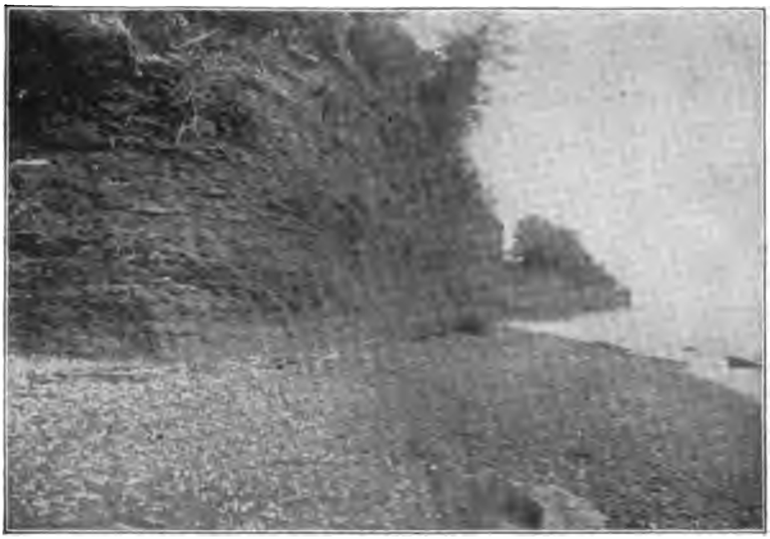

FIG. 169. A wave-cut cliff of shale, faced by a narrow pebble beach, at Westfield, New York, on the Erie shore.

base to summit, owing to the greater effect of weathering in the upper portions of the cliff. Such rock cliffs abound along the Erie and Ontario shores in New York, where the

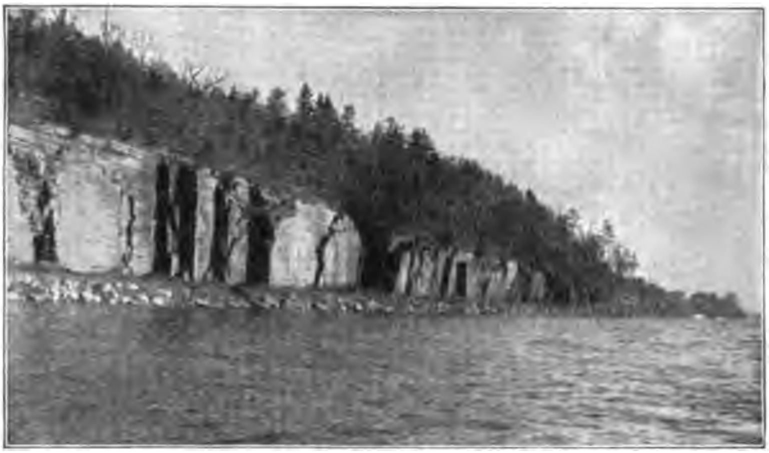

FIG. 170. Jointed face of a wave-cut shale cliff on the shore of Lake Cayuga, New York. The coast has been slightly modified by the building of a railway on the beach at the base of the cliff.

waves have been cutting into nearly horizontal strata (Fig. 169). Weathering and wave attack have often etched out the layers, causing the harder ones to stand out in horizontal sheets beyond the general cliff face. Joints in the rocks render them more open to wave attack, and their effect is often seen in the cliff form, which is frequently made up of a series of angles and smooth joint faces (Fig. 170). Where strata are inclined, much variety in coast form is produced by the nature of the inclination and the variation in the hardness of the strata.

In localities where the rocks vary in hardness from place to place alongshore the waves often etch out these differences, producing chasms and tiny bays in places where the rocks are softer. One often sees such wave-formed irregularities along the rocky New England coast. Numerous joints in a certain zone also give rise to indentations of this nature, as is frequently illustrated in the shale cliffs of the Erie shore; but such wave-cut bays are, of necessity, minor shore features, because as soon as a bay of slight depth is cut the waves wear themselves out by friction along its sides, thus losing force, and hence ability to cut further. No real large bays can be wave-formed.

Under favorable conditions waves are able to cut back on the two sides of a tiny promontory, and then, aided by weathering, to cut behind the end of this, leaving it as an island, or *stack*, entirely removed from the mainland (Fig. 172). The protected seacoast line of New York is unfavorable to the formation of many of these destructional features described above, and, for the most part, furnishes illustration of the opposite type of coast line, namely, that due to processes of construction.

CONSTRUCTIONAL FORMS.—The materials furnished to the waves and wrested by them from the coast cannot always be at once removed. Some of them accumulate at the base of the cliffs, or in the minor indentations of the shore line, forming beaches (Fig. 171). These become mills in which the waves are able to grind the rock fragments to such a size that they are more easily removed. All along the coast

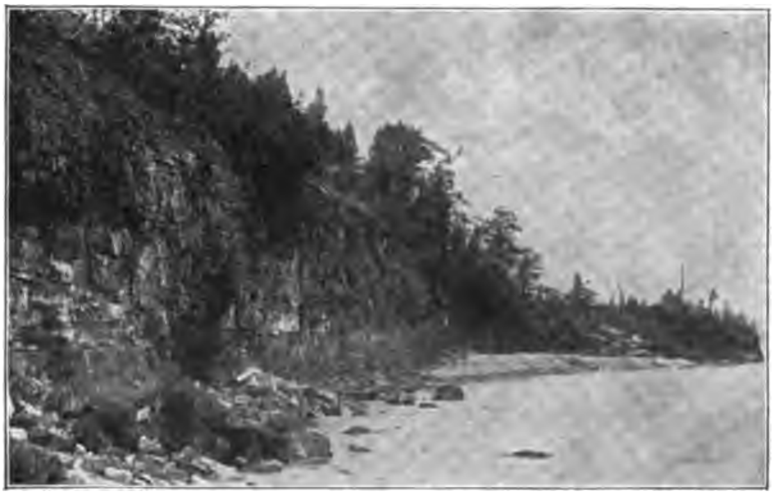

FIG. 171. A tiny pocket beach on the shores of Lake Superior, where the pebbles wrested from the cliffs have been driven into a protected angle in the coast.

line, both of the lakes and of the sea, there are beaches of this kind, some of them pebbly, others sandy. There is a decided variation in the form of the beaches under varying circumstances.

The simplest beach is that made of fragments from near-by cliffs (Figs. 166–169). Upon this the waves break, rolling the rock fragments to and fro and grinding them finer. By the aid of the undertow much of this ground-up material is removed and distributed over the bottom off shore, leveling the lake- or sea-bed; but much is also disposed of by being driven alongshore; for, when a wave breaks against the cliff or beach, unless it approaches *directly* upon the coast, its attack is diagonal to the trend of the shore, and with each breaking wave the fragments are pushed along the shore in front of the wave. When watching the breaking wave one is often able to see this movement of the pebbles;[1] and it is equally well proved by studying the transportation in the direction of maximum wave movement of rock fragments of some kind that can be easily identified.

Added to these two causes for the transportation of wave-derived materials, is the current-like movement of the water itself, produced by the wind; for, when the wind blows diagonally against or parallel to a coast a surface drift of water is produced, which moves alongshore in either one of the two directions, according to the wind direction. That is to say, the current moves either up or down the coast, and parallel to its general trend. This wind-formed current tends to drift fragments in the same direction that the breaking waves push them, and is, therefore, a support to wave action; but it must be considered of less importance than wave action, because it is never powerful enough to move any excepting the smaller fragments, while the breaking wave will transport good-sized pebbles, and even boulders, especially when imbedded in ice.

Since on every coast there is one direction from which the *average* wind-formed waves strike with greater force and persistence than from other directions, there is, of necessity, one direction in which the rock fragments are prevailingly moved. For instance, on the shores of Lakes Erie and Ontario the winds from the western quadrant are more frequent than those from the eastern, and so the rock fragments are moved farther toward the east than toward the west.[1] On Long Island, on the other hand, the west winds, blowing from the land, are much less effective than the east winds from the ocean, and the movement of particles is therefore from the east (Fig. 174).

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[1] Martin, Amer. Geol., XXVII, 1901, 331–334.

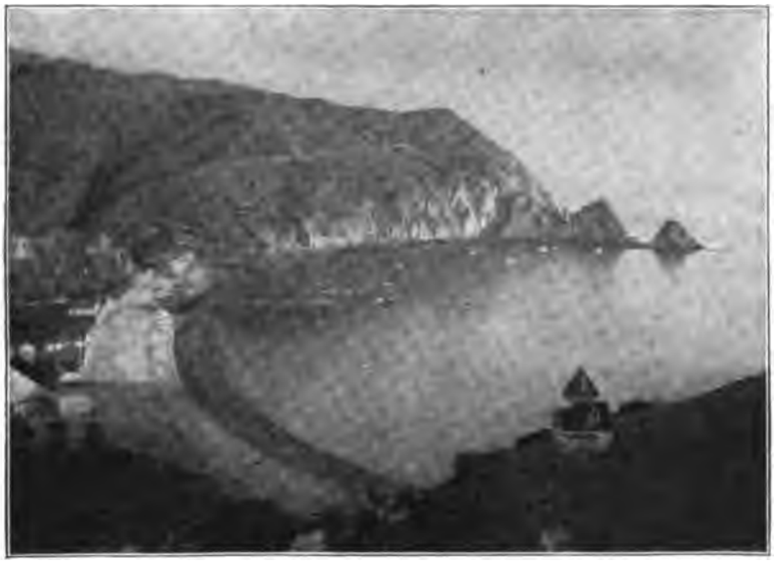

FIG. 172. The harbor of Avalon on Catalina Island, California, showing a beautiful crescent beach at the head of a bay into which fragments derived from the headlands are driven.

While we have considered only the movements resulting from wind and wave, it must not be overlooked that on the sea shore these causes for the movement of particles are sometimes aided, sometimes checked, or seriously modified, by the action of the tide. In some places tidal currents are so powerful that they furnish the dominant force in determining the coastal form. This is all the more liable to be true where the tidal currents are powerful, because such currents are, as a rule, much less well developed upon exposed coast than they are in the inclosed bays where wave action itself is normally weak and hence easily counterbalanced by even tidal currents.

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[1] Dewey, Amer. Journ. Sci., LII, 1846, 85–7; LIII, 1847, 444; Clark, Trans. Canad. Inst., II, 1890–91, 154–7; Harrington, Nature, XLIX, 1894, 592–3, and other articles referred to on page 3C1.

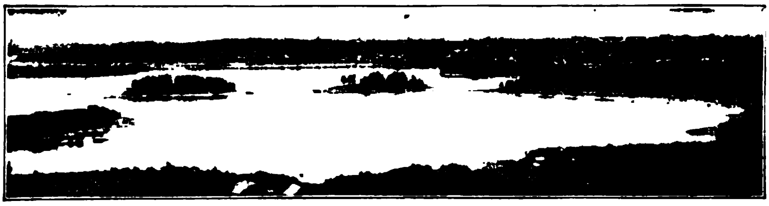

FIG. 173. The drowned coast of Maine, showing a part of Castine harbor, with peninsulas and islands, one of the latter being tied to the mainland by a bar built in the lee of the island.

The effect upon the coast form of these various causes for removal of wave-derived materials is very pronounced. Rock fragments from cliffs are often driven into little bays, where, in their protected position, they form pocket beaches (Figs. 171 and 172). Or, where the coast is more irregular, fragments may be driven from the exposed outer edges of an island around its margin to the protected rear, where, being out of reach of the waves, they form bars, which grow until, finally, the island is connected either to another island or else to the mainland (Fig. 173). These tied islands are sometimes connected with the mainland by a single bar; at other times by a double one.

In other cases, where the coast is indented by bays, the driving of the particles alongshore oftentimes builds a bar from the margin of the bay out across the indentation (Figs. 174, 181 and 182). Such growing bars will be found on almost all irregular coasts, sometimes so poorly developed that they would not be noticed, excepting upon a carefully constructed contour map; or, in other places, forming pronounced shoals, dangerous to navigation and requiring the location of buoys and even lights to mark their dangerous positions. When still further developed, these bars rise

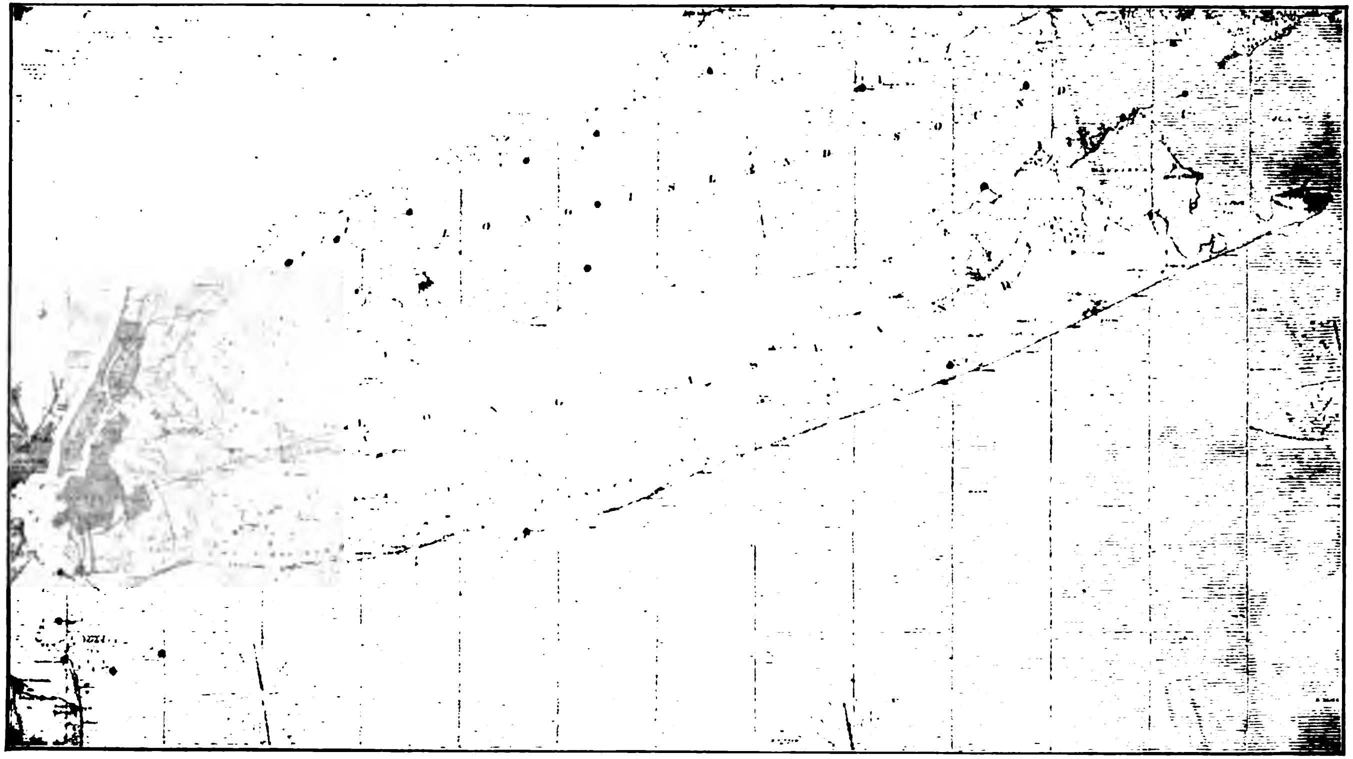

FIG. 174. The Long Island coast, showing the long Fire Island bar, reaching westward and replacing the irregular coast by a straight beach

well above the water, either partly, or, in many cases, completely inclosing the bay. Along the southern shore of Long Island excellent illustrations of various stages of this bay-closing are found (Fig. 174).[1] The long bar of Fire Island beach is an excellent illustration of this, the fragments from which it is made having been derived by the waves from eastern Long Island and driven westward by the winds and waves, perhaps aided by tidal currents.

In the construction of such bars as this, the waves first of all drive the fragments along and heap them up to the height which the higher waves reach. This makes a bar in the sea, whose surface is exposed to the air under ordinary conditions of weather, being reached by the waves only when the heaviest storms prevail. On some coasts the bars are of pebbles; but along the Long Island shore they are made of sand. During the interval of exposure to the air, the sand particles are dried and brought under the influence of the winds, which drift them about, broadening the bar and raising its surface higher, until, finally, habitable land is made in the sea (Fig. 175). By this combined action of waves and wind, which piles the sand into narrow strips, a

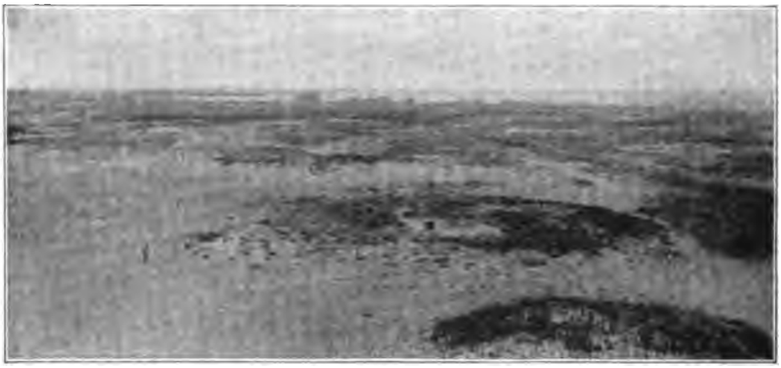

FIG. 175. The surface of the bar of Monomoy Island on the Massachusetts coast, a bar built up by the waves and wind. Under the influence of the latter the sand is still shifting about.

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[1] Rogers, Rept. Brit. Assoc., IV, 1834, 11; Mather, First Rept. Geol. of New York, 1837, 76–84; Second Rept., same, 1838, 125–133; Mather, Geology of New York, 1st Dist., 17–33; 234–235.

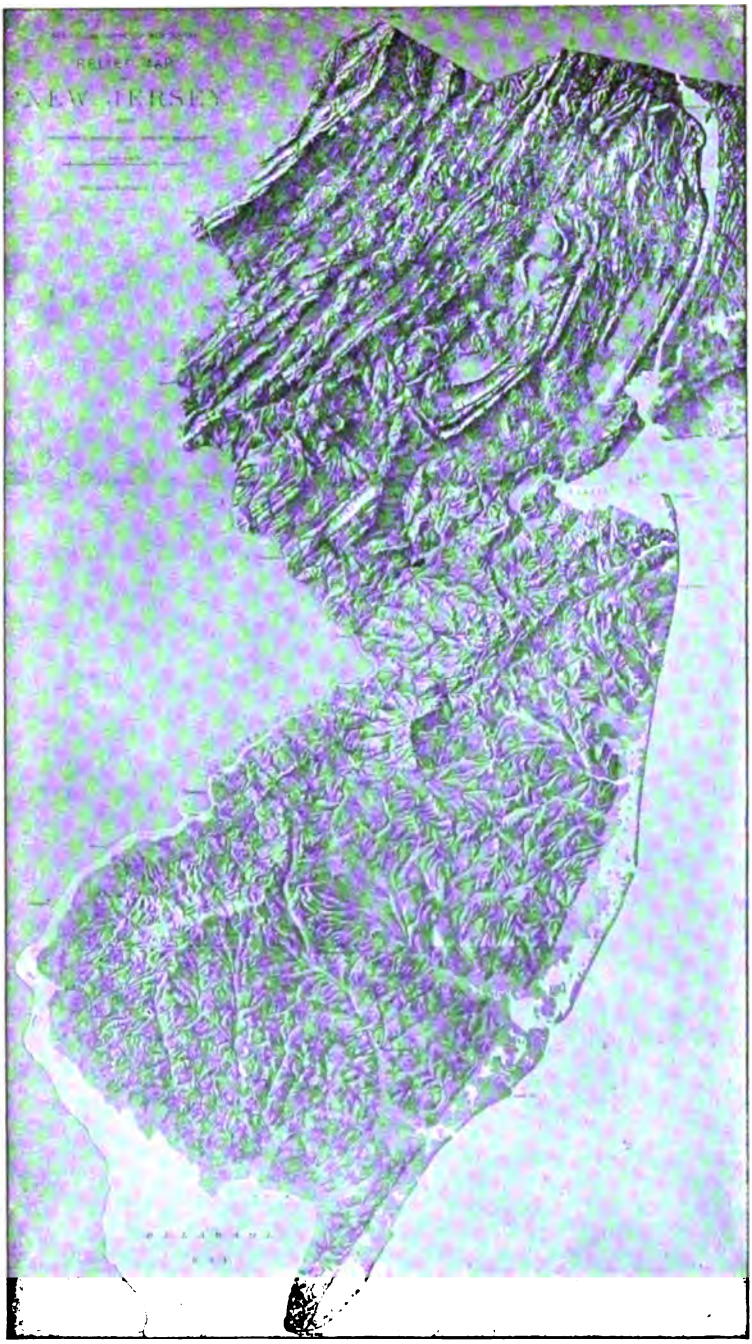

FIG. 176. A relief map of New Jersey showing the drowned coast near New York, the cliffs south of New York, the bars formed by the waves, the salt marshes behind them, and the cliffs of the old land behind these. (New Jersey Geological Survey Map).

vast amount of land has been made that is of use for purposes of summer resort and for the homes of fishermen. The surface of these wave- and wind-constructed bars is usually made of loose sand, irregular in form and frequently changing in outline under the influence of the variable winds. Sand-dunes, like these in outline, are not confined to the bars that have been built *in* the sea. They are also found bordering the coast, as, for instance, on the sandy shores of Long Island.[1]

Sandy Hook (Figs. 176, 177 and 178) furnishes another illustration similar to the Fire Island beach. On the New Jersey coast the effective wave-forming winds blow from the southeast and northeast,[2] and the materials which these waves derive are drifted along the coast, northward by the southerly winds, and southward by the northerly winds. Owing to the predominance, or rather to the greater effectiveness, of the northeast winds, the best bar is that developed south of Ocean Grove in the direction of Barnegat; but an excellent bar is also developed on the northern end, forming Sandy Hook. Here the winds from the northeast cannot produce a great effect, because of the protection furnished by the land to the north of the Sandy Hook region; but the waves and winds from the southeast, having a much larger stretch of water to blow over, *are* effective, and the sand has been driven along before them. Tidal currents have doubtless had much influence in determining the form of Sandy Hook, especially in influencing its westward turn, although probably the principal cause for this is the power of the east wind, which has turned the end of the bar landward.

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[1] Mather, Geology of New York, 1st Dist., 30–32; 233–4.

[2] Bache, Proc. Amer. Assoc. Adv. Sci., X, 1856, 171–2; Bache, Amer. Journ. Sci., LXXIII, 1857, 16–17; Bache, Proc. Amer. Assoc. Adv. Sci., XII, 1858, 80–92; Bache, Amer. Journ. Sci., LXXVI, 1858, 334–342; Appendix, 27, U. S. Coast Survey Report, 1858, 197–203; Mitchell, Science, IX, 1887, 204–5; Cook, Annual Rept. New Jersey Geol. Survey, 1882, 80–83; Cook, Annual Rept. New Jersey Geol. Survey, 1885, 57–96; Davis, Proc. Amer. Acad. Arts and Sciences, XXXI, 1896, 303–332; Gulliver, Proc. Amer. Acad. Arts and Sciences, XXXIV, 1899, 151–258. For reference to a number of other papers on New York harbor and vicinity, many published in U. S. Coast Survey Reports, see Nat. Acad. of Science Biographical Sketches, Vol. I, 1877, 205–212 (bibliography of A. D. Bache).

Before Sandy Hook had been built out to its present position in front of the Navesink Highlands, the ocean waves beat directly upon the New Jersey coast and cut the cliff which faces the seaward side of this highland (Figs. 176 to 178). With the constant supply of material from the cliffs to the south, driven alongshore by winds, waves and tides, the bar has reached further and further northward, until it has so compassed the Navesink region as to protect the cliffs from further attack by the waves. In geographic nomenclature such a growth of land in the sea as is represented by the Sandy Hook and Fire Island bars forms the *new land*, in contradistinction to the *old land*, of which the Navesink Highlands may be taken as a type. Through the action of the waves and winds, in a manner similar to that which has been briefly sketched here, a vast amount of new land has been built, in the form of off-shore bars, from New York City southward to the Rio Grande.

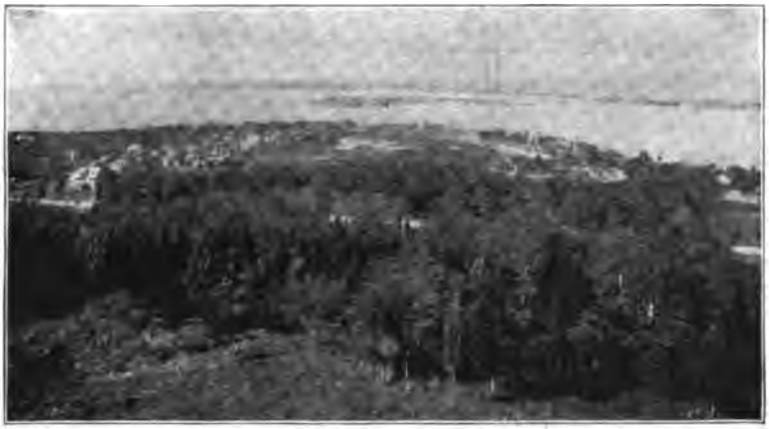

Fig. 177. View of Sandy Hook from Navesink Highlands showing the bar protecting the old sea cliff, from which the picture was taken.

There are, besides these that have been mentioned, numerous other forms assumed by bars. In some places, for instance, a *spit* grows directly out from the land[1] where, at a turn in the lake, the opposing winds drive fragments before them, and, in the conflict of forces, build the bar out-

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[1] Tarr, Amer. Geol., XXII, 1898, 1-12.

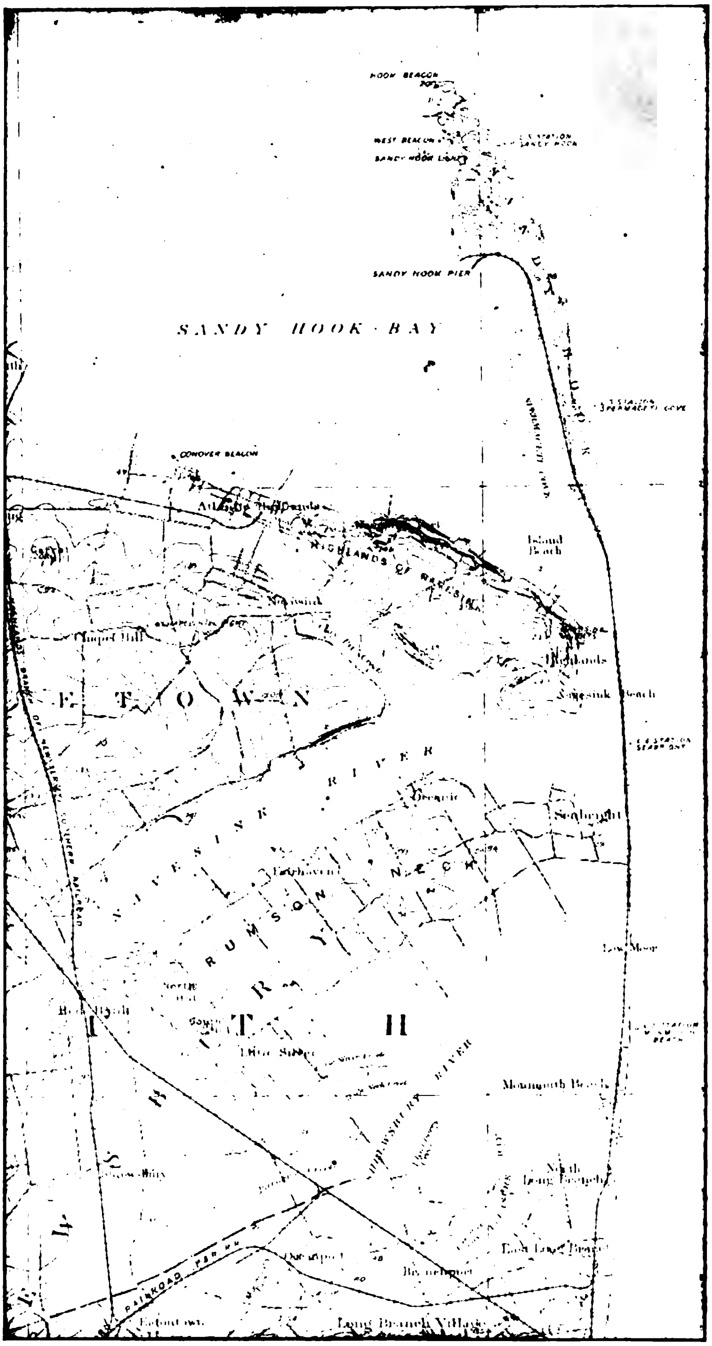

FIG. 178. The bar of Sandy Hook stretching from the cliffs south of Long Branch past the bays of the drowned coast and in front of the sea cliffs of Navesink Highlands.

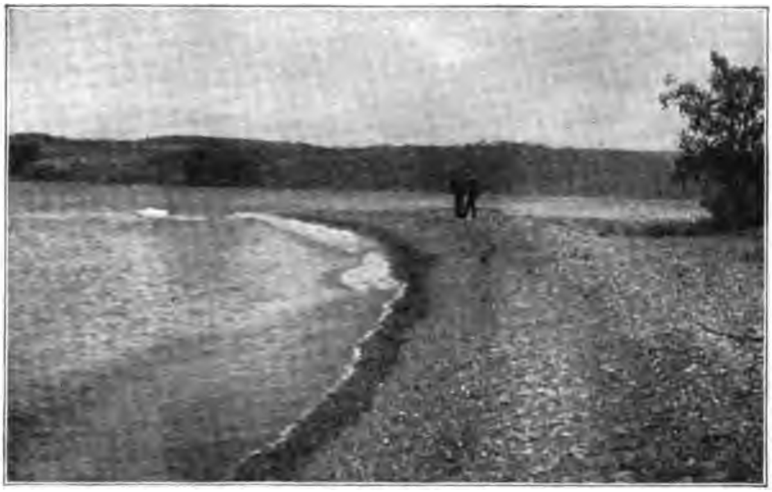

FIG. 179. Crow Bar point, a spit built out from the shores of Lake Cayuga, New York, at a bend in the lake.

ward (Fig. 179). Elsewhere the spit is curved at the end, forming a *hook*. There are also V-shaped bars, called *cuspate forelands*,[1] with the angle of the V projecting outward. Small cusps occur on many coasts, and larger cuspate forelands are represented by Capes Hatteras, Canaveral and Fear. Deltas opposite the mouths of streams which enter

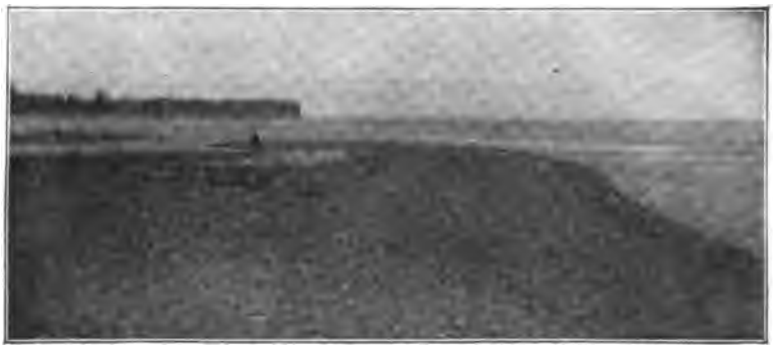

FIG. 180. A hooked bar, formed by the waves modifying part of a delta on the Erie shore at Silver Creek, New York.

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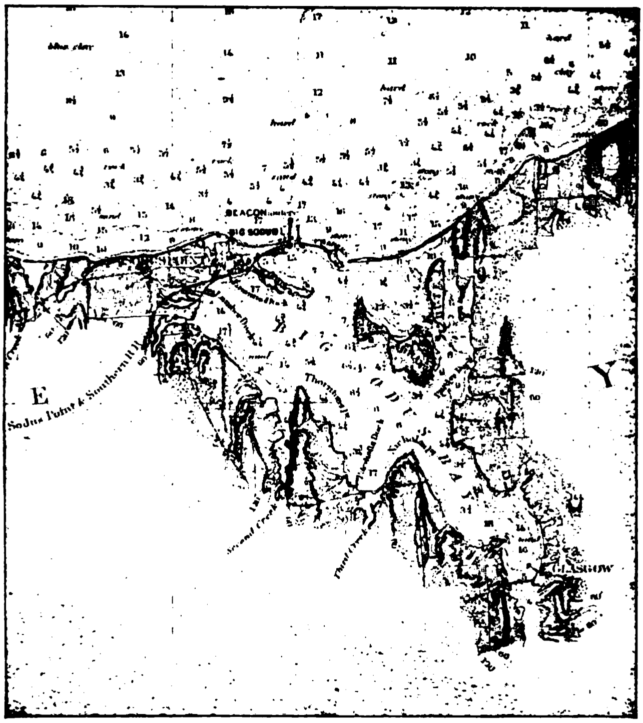
[1] Abbe, Proc. Boston Soc. Nat. Hist., XXVI, 1895, 489–497; Gulliver, Bull. Geol. Soc. Amer., VII, 1895–96, 399–422; Gulliver, Geog. Journ., IX, 1897, 536–546; Gulliver, Proc. Amer. Acad. Arts and Sciences, XXXIV, 1899, 151–258; Tarr, Amer. Geol., XXII, 1898, 1–12.

lakes or bays along the seacoast are often modified by waves and currents until they lose their symmetry of form, and, at least in part, become bars (Fig. 180). In a discussion limited as this is it would be impossible to present a complete analysis of wave work and bar construction, so that no attempt is made to explain the numerous variations from these types which have been briefly described.



FIG, 181. Bars enclosing the Big Sodus Bay on the Ontario shore.

STRAIGHTENING OF THE COAST.—The effect of the growth of bars along an irregular coast is to straighten it, as one may readily see by examining a map of the Long Island or New Jersey shores (Figs. 31, 174, 176 and 178). The headlands are cut back, bars are built across the mouths of bays, and the bays themselves are frequently filled and obliterated by the supply of material brought into them by streams from the land, by winds, by waves and by tides.

Sediment from the land has been dumped behind the bars of the New Jersey and Long Island coasts, and the sounds have become gradually filled, so that, in some places, at low tide, there is direct communication between the offshore bar and the old land. Upon the sandy and muddy bottoms of inclosed bays which are being thus filled by incoming sediment, marsh grass takes root and aids in the completion of the process of transforming the bay to a level, swampy plain (Figs. 31, 32, 176 and 183). This is at first traversed by numerous channel-ways and covered by the high tide; but ultimately it is transformed to a level plain, which is reached only by the very highest tides of the year, and, later, is gradually built beyond the reach of even these.[1]

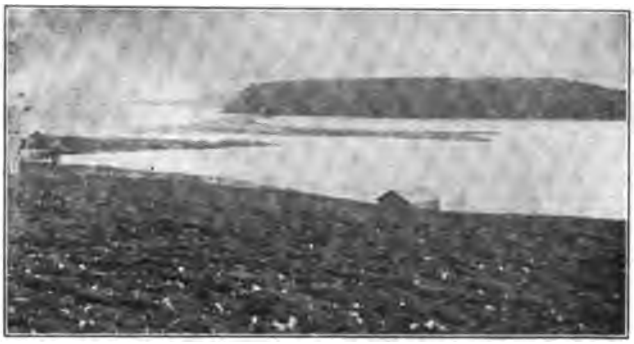


FIG. 182. Bar enclosing a bay at North Fairhaven, on the Ontario shore.

These salt marshes (p. 75), when they have reached well along toward completion, are well adapted to use as farming land, if only the salt water can be excluded. Owing to the cheapness of farming land in this country, little has been done to utilize the vast resources of salt marsh, much of which is located within easy reach of some of the large cities. There are vast tracts of such land, which might readily be reclaimed, within a few miles of New York City, and hundreds of thousands of acres at other places along the seacoast. While little has been done in this respect in the United States, other parts of the world furnish excellent illustration of the possibility of reclaiming this land from the sea. On our own continent, the largest areas are those in the Bay of Fundy (Fig. 184) (the land of Evangeline), which were reclaimed by the Acadians, and which now form some of the best farming land in the eastern Provinces. In Europe a great deal of salt marsh has been reclaimed in England, Belgium, Holland and elsewhere. In Holland the reclamation has gone so far as to extend beyond the zone of marsh grass growth and include the muddy bay floor; the reclamation of the salt swamps of New Jersey will be accomplished in the future. Full descriptions of the New Jersey marshes and the possibilities of their reclamation will be found in the reports referred to below.[1]

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[1] Mather, Geology of New York, 1st Dist., 17–19, 234; Cook, Geol. Survey New Jersey, Cape May Report, 1857, 15–65; 91–94; Cook, Annual Rept. New Jersey Geol. Survey, 1869, 23–41; Cook, Geology of New Jersey, 1869, 300–308; Cook, Annual Rept. New Jersey Geol. Survey, 1885, 61–70; Smock, Annual Rept. New Jersey Geol. Survey, 1892, 213–353; Vermeule, Annual Rept. New Jersey Geol. Survey, 1896, 289–317; Shaler, Sixth Annual Rept. U. S. Geol. Survey, 1885, 353–398.

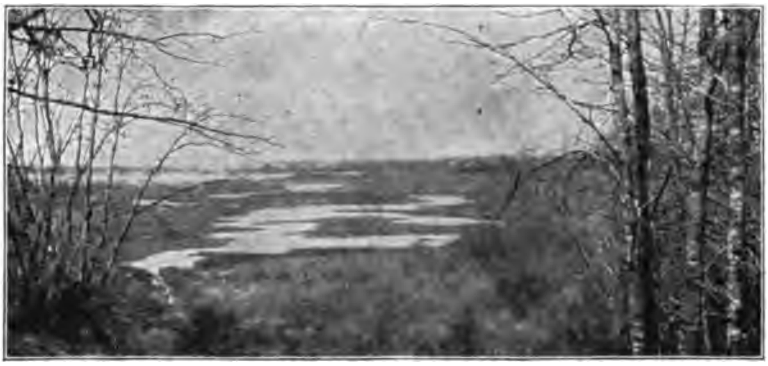

FIG. 183. A salt marsh forming behind a sand bar at Bourne on the Massachusetts coast.

If the land were to remain long enough at the present level the Hudson estuary would become partly filled, much as some of the neighboring shallow bays have already been, and the water area would be narrowed and the depth decreased. In fact, New York Bay would also become transformed to a plain traversed by a few channels for conducting off the fresh water from the land, while even Long Island Sound itself would finally suffer the same fate. Doubtless before such fate shall have come, the rising or sinking of the land will have changed the conditions of the coast line so completely that the effect of filling will be masked; but even within historic times the measurements of the breadth and depth of bays have shown that they are in process of filling, as a geologist would have decided, with equal certainty, on the basis of the geological fact that materials are entering the bays in excess of the ability of the oceanic agents to remove them. This work of filling is so rapid that in many harbors constant effort is necessary to prevent the encroachment of land upon the sea and to maintain the harbor in good condition. How much the filling amounts to in the case of individual bays along the lake shore and sea shore of New York, it is too early to state, for careful measurements have not been made through a long enough period of time to determine this; nor are we able to say whether the movement of the land, which is *apparently* in progress, and which is estimated on the New York shore to represent a

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[1] Cook, Geol. Survey New Jersey, Cape May Report, 1857, 15–65; 91–94; Cook, Annual Rept. New Jersey Geol. Survey, 1869, 23–41; Cook, Geology of New Jersey, 1869, 300–308; Cook, Annual Rept. New Jersey Geol. Survey, 1885, 61–70; Vermeule Annual Rept. New Jersey Geol. Survey, 1896, 289–317; Shaler, Sixth Annual Rept. U. S. Geol. Survey, 1885, 353–98.

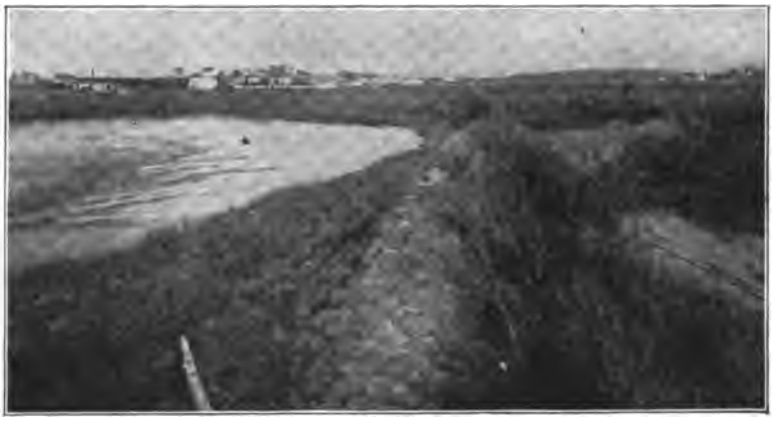

FIG. 184. A dike for reclaiming salt marsh in the Bay of Fundy.

sinking at the rate of about two feet a century, will be sufficiently great to overcome the process of filling, which is *certainly* in progress.

Elsewhere in the world other forms of life than the marsh grasses aid in the production of land in the sea. It will not be possible to enter into a consideration of these in detail, but merely to mention them. The most important plants are those peculiar trees, the mangroves, which grow in tropical lands, producing swamps, much as the marsh grass of the northern States causes swamps in the inclosed areas. In this country we have tree-covered mangrove swamps on the Florida peninsula, and they are abundant along many other tropical coasts. The tree-covered swamp predominates in tropical regions, treeless marshes in temperate latitudes, and both are absent in the Arctic. During the coal period there were doubtless tree-covered swamps in southern New York, as there were in Pennsylvania, though now, by erosion, even the beds of coal which they formed have been removed from New York.

CORALS.—Many animals are engaged in the work of land-making, but none are so noteworthy as the corals, which, aided by other lime-secreting animals, have made so many reefs and islands in the sea. The southern end of Florida and the Keys south of that peninsula, as well as the Bermuda and Bahama Islands, and the borders of some of the West Indian islands, such as Cuba and Porto Rico, are illustrations of the work of animal life in land construction. Here, as in the case of sand bars, the work of waves in raising the fragments into the air and of winds in blowing them still higher, are important features in the construction of land; for the animals themselves, which secrete the material, are able to grow only beneath the water surface. Since none of these forms of life are at present effective as land builders in New York, no further discussion of them seems called for here.

ELEVATED SHORE LINES.—As has been shown in previous pages (p. 131 and Chapter VIII), there are in various parts of New York evidences of former higher levels of lakes, particularly along the shores of the Great Lakes. These are in the form of well-defined deltas, beaches and bars, with some wave-cut cliffs. They were formed during higher levels of the lakes, and now stand as the principal witnesses of these former higher levels.

Also shore lines of marine origin are found in the St. Lawrence Valley and in the Champlain-Hudson depression. Those in the Hudson Valley are not in the form of well-defined beaches, but distinct beaches are found in the St. Lawrence and Champlain Valleys, and the discovery of marine fossils in them proves that they were formed below sea-level. Since the depression in the north was greater than in the south, the ocean shore lines reach to higher levels in the northern than in the southern parts of New York. This is true along the Hudson (189 and 263), where the elevation of the marine deposits at Albany is 340 feet and near New York 80 feet. While it cannot be considered as positively proved that all of the terrace deposits along the Hudson are marine, or, rather, estuarine in origin, the work so far done upon them points towards the conclusion that in some cases, as, for instance, the deltas from the Catskill to Albany, the origin is estuarine.

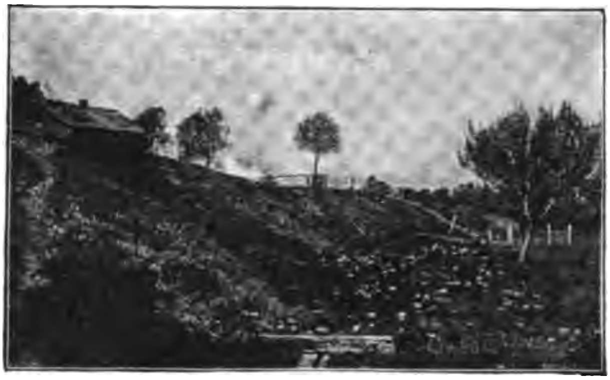

FIG. 185. An old beach on the shores of the Great Lakes.

Far back in geological time there have been other periods when shore lines within the boundaries of the State have been elevated above the level of the sea. The conglomerates of the Catskill Mountains, for instance, represent beaches of Devonian age, and there are still other shore lines preserved among the Silurian and Devonian rocks. Indeed, even before this time, near the beginning of the Paleozoic, the sea carved cliffs along the flanks of the Adirondacks and built beaches (p. 24) from the pebbles thus wrested from the land. This is proved by the fossil beaches preserved among the consolidated strata of Cambrian age.

These elevated beaches furnish proof of the instability of the land, and make it still more easy to understand the changes which have brought about the irregularities due to land-sinking that have been mentioned earlier in the chapter; and they make it easier to believe in the possibility of still further changes in the future, which may so modify the coast near the City of New York as to greatly modify its political and commercial importance.

CHAPTER XI

THE CLIMATE OF NEW YORK

By E. T. TURNER

Basis for a Study of New York Climate.—The State of New York affords an exceptionally favorable and interesting field for the study of climate, owing to the diversity of its physical features, as well as to the wide variety of atmospheric influences to which it is subject. It is not surprising, therefore, to find that the first organization for local climatic observation in America was that inaugurated in 1826 by the New York Board of Regents at numerous academies under their supervision, and which was continued without a break at several stations until 1863. After that time meteorological records were maintained by a few scattered observers coöperating with the Smithsonian Institution; and in 1870–71 five fully equipped stations were established in the principal cities by the United States Signal Service.

The State Weather Bureau was created by act of the Legislature in 1890, and, with the aid of over one hundred voluntary observers, its work was carried on for ten years, when the organization passed under the control of the National Weather Bureau. A great mass of data has thus been accumulated for the use of the climatologist, and may be found in the various publications mentioned in the footnote;[1] but in view of the improvements which have of late years been made in instruments and method of observation, the investigator will find it best to depend upon the later observations, as far as practicable, and especially so when *dealing with temperature values.*

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[1] Essay on the Climate of New York, by F. B. Hough, Albany, 1857; A Letter on the Climate of New York, by J. H. Coffin, contained in the Natural History of New York State, Albany, 1843; Climatology of the United States, by Laurin Blodgett, Philadelphia, 1857; Observations of the New York Board of Regents, Albany, 2 vols.; Atmospheric Temperature and Precipitation in the United States, by C. A. Schott, Smithsonian Contributions to Knowledge, Washington, 1876 and 1881; Monthly Reports of the United States Signal Service and Weather Bureau, Washington; Monthly Reports of the New York Weather Bureau, Ithaca; The Climate of New York State, by E. T. Turner, contained in the 5th and 9th Annual Reports of the New York Weather Bureau, Albany.

GENERAL FEATURES OF CLIMATE.—Glancing briefly at the general features of terrestrial climate and air circulation, which govern and include our local conditions, we have first to consider the effects of geographical position upon temperature, as shown in the accompanying isothermal charts of the northern hemisphere. The position and trend of the lines of equal temperature are determined by three factors:

[1] ISOTHERMAL LINES OF THE NORTHERN HEMISPHERE AND WINDS OF THE UNITED STATES

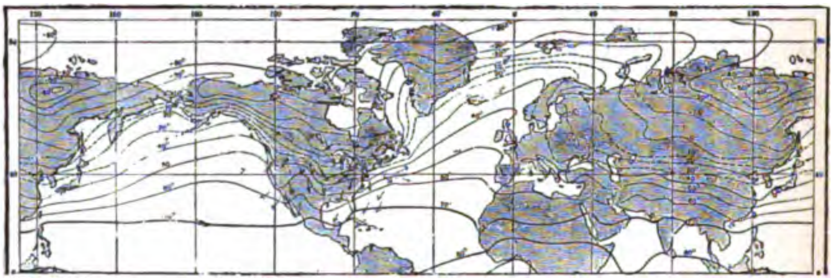


FIG. 186. January.

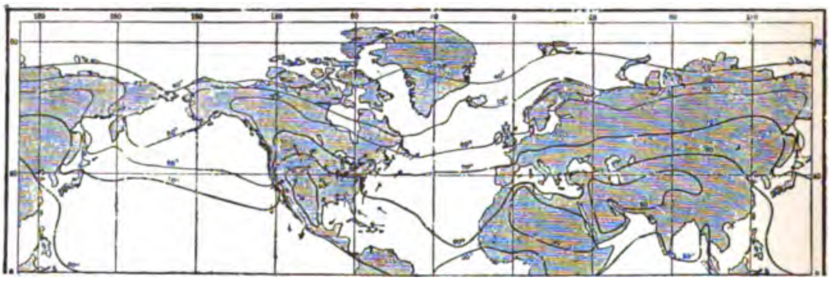


FIG. 187. July.

Firstly, the decrease of temperature which occurs as we proceed northward. The average rate of this is 1° F. of annual temperature per degree of latitude.

Secondly, the rapidity of absorption and radiation of heat from land surfaces, as contrasted with the thermal stability of bodies of water. The difference between midsummer and midwinter temperatures in the interior of the American continent and over the Atlantic, at our latitude, is shown approximately as follows:

---

[1] Fig. 186—The line of 20° passes through northern New York. Fig. 187—The line of 70° passes through central New York.

	MEAN FOR JANUARY	MEAN FOR JULY	RANGE OF MO. MEANS	RANGE OF EXTREMES
Atlantic	50	66	16	27
Interior	8	72	64	126

There is also quite as marked difference in the *daily* range of temperature between the land and the ocean.

Thirdly, the transfer of air from region to region, by means of the atmospheric circulation, tends in a marked degree to diffuse and equalize climatic conditions. The most important of these wind systems are as follows:

(*a*) The southwesterly winds which prevail over the temperate zone, in consequence of the heat circulation between high and low latitudes, conjoined with the earth's rotation. These may be called *Planetary Winds.*

(*b*) Winds of the monsoon type, blowing landward in summer and seaward in winter, as the result of unequal thermal conditions of continents and oceans.

(*c*) Winds accompanying those rapidly shifting areas of high and low barometer, known, in their most pronounced form, as cyclonic storms and anticyclones, respectively (see Fig. 189, page 336); air flowing *toward* centers of low pressure, and *out from* centers of high pressure. It is important to note, in this connection, that in the northern hemisphere the rotation of the earth tends constantly to deflect air currents toward the right of their direction of motion; hence the circulation about high and low areas is not direct, but spirally inward and outward.

The general westerly circulation (*a*) evidently must tend to bring the moisture and equable temperature of the ocean well inland over the western sides of the continents, as we find to be the case on our Pacific slope and along the northwest coast of Europe; while in a similar manner the conditions of the continental interior will more generally prevail along the eastern coasts. The two cases are fairly presented by the following:

TABLE OF MEAN TEMPERATURES

		MIDSUMMER	MIDWINTER	DIFFERENCE
West Coast.......	San Francisco....	60°	50°	10°
Interior............	St. Paul...... ..	72	8	64
East Coast.........	New York City...	74	31	43
West Coast........	London, Eng.....	64	38	26

The monsoons (class *b*) in winter strengthen the dry, cold winds from the interior eastward toward the ocean, but in summer tend to reverse the east-moving current; hence we must expect the continental type of climate to be much more strongly felt over the eastern States in winter than in summer. It must be noted, however, that the summer monsoon does not reach us directly as a cool sea-wind, since it is not strong enough to overcome the eastward drift until we approach the southern States and Mexican Gulf; but passing inland, over that semi-tropical region, it unites with the general current, and reaches us as the warm and moist southwesterly wind of summer, giving the abundant rainfall characteristic of that season.

Finally, the temporary winds of class *c* are responsible for the *variability* of weather which is so marked a feature of our climate. The low barometer areas of America move eastward at an average rate of 800 miles per day, and in the large majority of cases pass centrally over the vicinity of the Great Lakes and St. Lawrence Valley, drawing in masses of air from the ocean and the south, at the same time giving rain or snow over the northeastern States. These disturbances recur at intervals of three or four days, on an average, in winter, but with less frequency and strength in summer. They are generally followed by high-pressure systems from the interior, whose outflowing winds are characteristically dry and cold; so that, in fact,

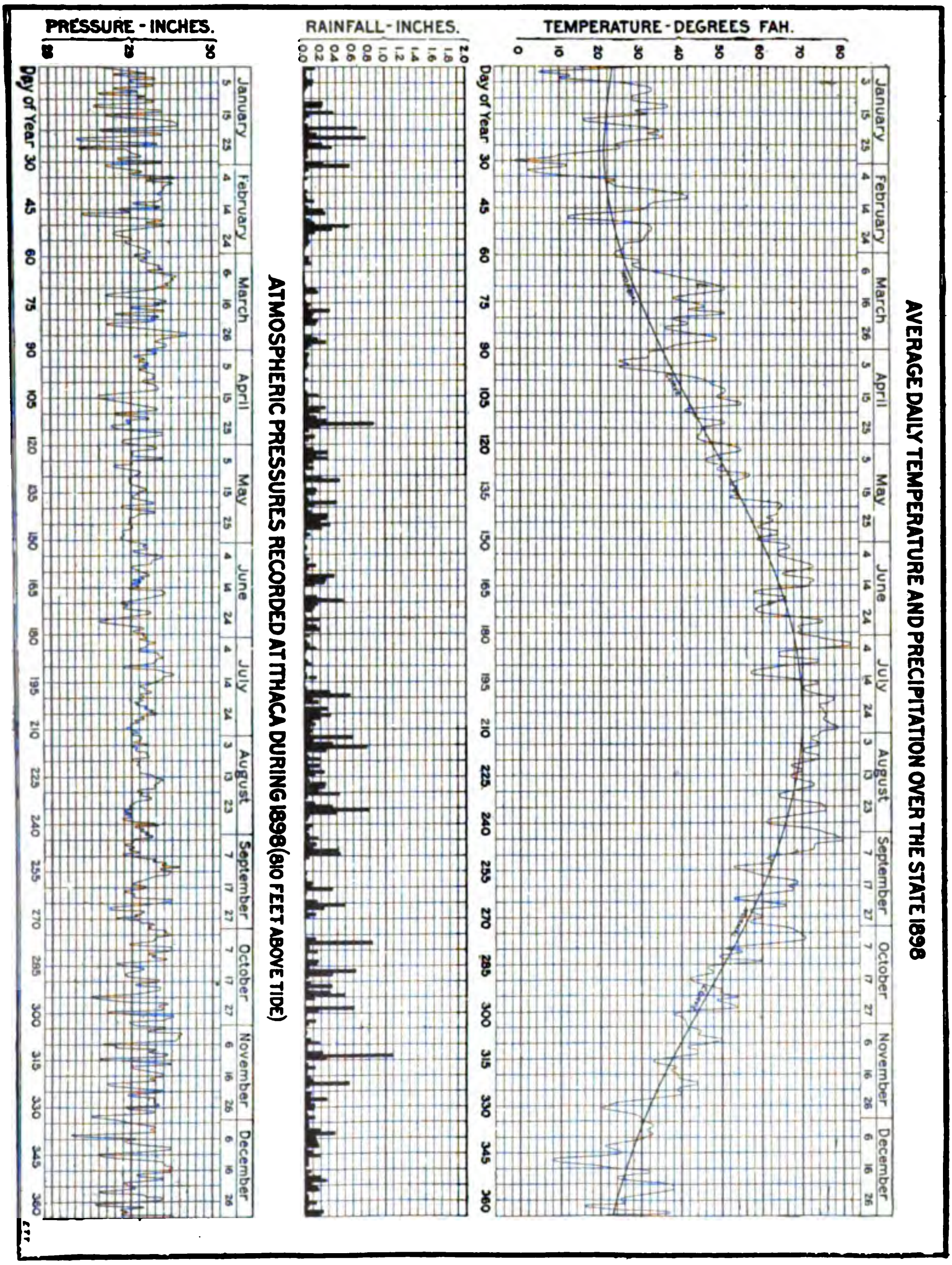
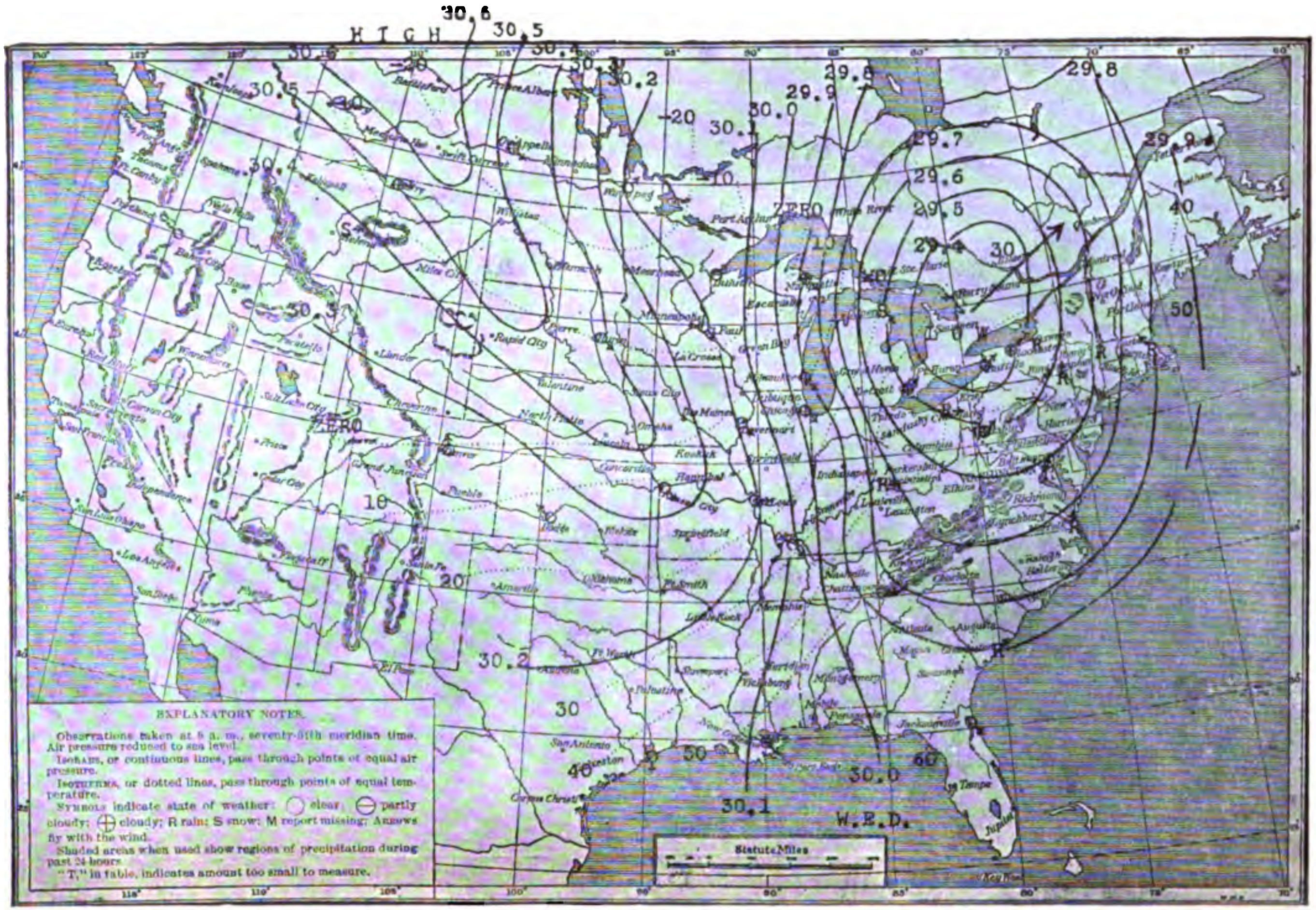

AVERAGE DAILY TEMPERATURE AND PRECIPITATION OVER THE STATE 1898
TEMPERATURE - DEGREES FAH.
0
10
20
30
40
50
60
70
80
RAINFALL - INCHES.
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
ATMOSPHERIC PRESSURES RECORDED AT ITHACA DURING 1898 (810 FEET ABOVE TIDE)
PRESSURE - INCHES.
28
29
30
January
February
March
April
May
June
July
August
September
October
November
December
Day of Year 30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
270
285
300
315
330
345
360

FIG. 188.



EXPLANATORY NOTES.

Observations taken at 8 a. m., seventy-fifth meridian time. Air pressure reduced to sea level.

ISOBARS, or continuous lines, pass through points of equal air pressure.

ISOTHERMS, or dotted lines, pass through points of equal temperature.

SYMBOLS indicate state of weather: ○ clear; ⊖ partly cloudy; ⊕ cloudy; R rain; S snow; M report missing; ARROWS fly with the wind.

Shaded areas when used show regions of precipitation during past 24 hours.

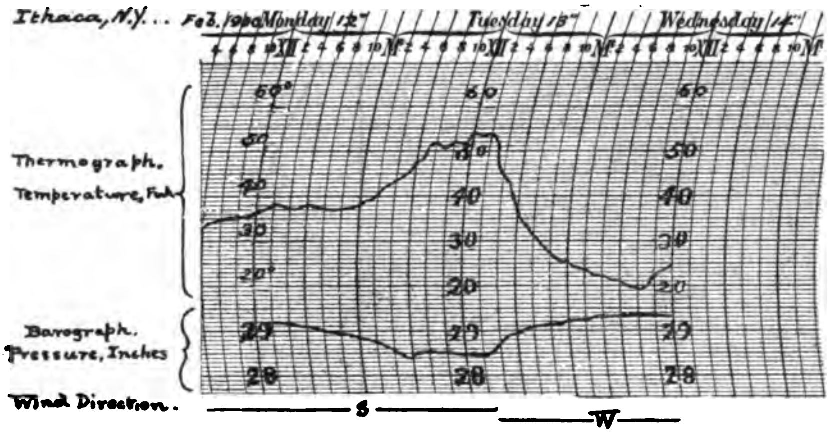
"T," in table, indicates amount too small to measure.

FIG. 189. Weather map, February 13, 1900

our winter climate is made up of constant alternations of maritime and continental conditions.

Figure 188 shows graphically the fluctuations of temperature and weather to which New York is subject, and their close relation to the passage of high and low barometer areas near the State. (It should be noted that the temperatures indicated by the wave-line are the daily averages for the entire State, and not the local extremes of heat and cold.)

The conditions attending a cyclonic storm and the succeeding anti-cyclone are shown by the accompanying weather-map (Fig. 189) for 8 A. M., February 13, 1900. The tracings of the self-recording barometer and thermometer at Ithaca on the same date are reproduced in Fig. 190, together with the wind direction. It will be seen that the approach of the storm, indicated by a falling barometer, gave southerly winds and rising temperature until 2 P. M., when the storm center passed nearest the station. The wind then immediately shifted to the westward, increasing in force, and at the same time the temperature fell, at first very suddenly and then gradually, until the crest of the "high" passed on the following day.



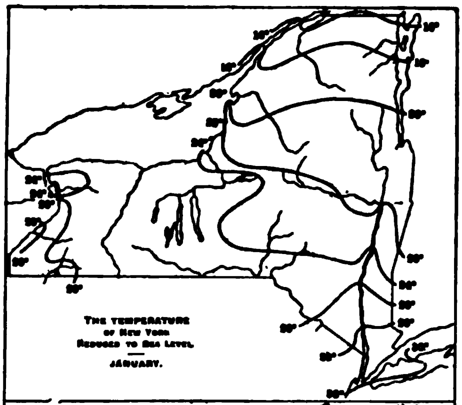
Temperature Pressure and Wind Direction at Ithaca. Feb 12th to 14th.

FIG. 190.

The element technically known as *variability* of temperature, i. e., the average difference from day to day, amounts to over 10° in Maine and Quebec for the month of January, when the maximum value is reached. The mean value for New York State is 8°; over the South Atlantic and Gulf coasts, 6°; on the coast of California, 2°.

In the immediate vicinity of our coast the greater part of the annual precipitation occurs in winter, when the low areas are most frequent and intense, but in the interior of the State heavy local rains during the period of the summer monsoon bring the maximum fall of the year at that season.

FIG. 191.



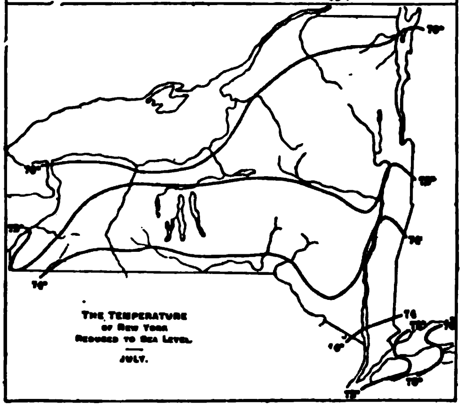


FIG. 192.

INFLUENCE OF GREAT LAKES.—We have thus far omitted to mention the important modifications of our climate due to the Great Lakes. These bodies of water follow the seasonal temperature changes much more closely than does the ocean, owing to their smaller mass; but nevertheless such scanty data as have been gathered indicate that the surface of Lake Ontario averages from 10° to 15° warmer in winter and cooler in summer than the adjacent land areas; hence the northwesterly winds of winter, in passing over the lake, are raised to a temperature considerably higher than obtains on the north shore. This influence is felt throughout the portions of the State lying to the south and east of the lakes, although decreasing rapidly as we proceed inland. In northern New York, on the other hand, the coldest winds of winter are not affected by the lakes, and in consequence the winters are much more severe than could be expected as a result of the higher latitude of the region alone. The southerly winds which predominate during the warmer portion of the year, of course, reach this State uninfluenced by the lakes, hence the temperature conditions are much more uniform over our entire area than in winter. The tempering effect of the lakes and ocean is clearly brought out by the accompanying isothermal charts, from which other sources of variation have been largely eliminated by reduction of temperatures to sea-level.

LOCAL CLIMATE

TOPOGRAPHICAL FEATURES.—The main portion of New York State is a broken and irregular plateau, whose average elevation is 1,200 to 1,500 feet above tide. This plateau is bordered on the west and northwest by considerable tracts of level lowland along the shores of the Great Lakes and the St. Lawrence River; while near the eastern border the valleys of the Hudson River and Lake Champlain form a deep channel extending from the seaboard directly northward into Canada.

Along the western side of this depression the highlands reach their greatest elevation in the mountain systems of the Adirondacks, Catskill, and several minor ridges; while on the east also the valley is closed in by the high hills of New England. The Hudson Valley is united to the lowlands of the Great Lakes by the narrow valley of the Mohawk, which divides the central plateau from that of the northern or Adirondack region. Among the more important minor depressions are the valleys of the Central Lakes and those of the Delaware and Susquehanna Rivers and their tributaries.

Elevations and depressions of land surface affect temperature conditions in three important ways:

First, the temperature average for the day (24 hours) decreases with elevation at the rate of about 0.3° and 0.4° per hundred feet in winter and summer, respectively. This rule should give to the plateaus a temperature 4° to 6° lower than that at sea-level.

Secondly, the highlands act as a shelter or windbreak for the neighboring valleys; and this effect becomes very important in a territory so irregular as that of New York. The temperate climates of the various "fruit belts" of the State are due both to a sheltered situation and to the proximity of bodies of water.

Thirdly, a flow of cold dense air from the hill slopes to the valley bottoms occurs on clear, still nights, and frequently so much reduces the temperature of the lowlands as to cause severe frosts, which are escaped at higher levels; and, since the highest midday temperature also occurs in the valleys, their daily range is often excessive. The following example of the conditions in central New York during a cold wave will sufficiently illustrate this point:

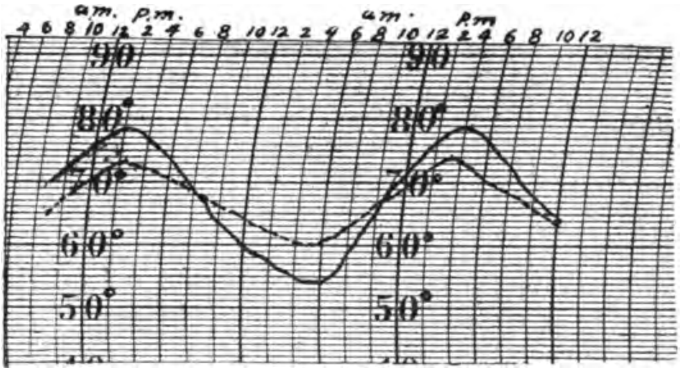
TEMPERATURE (FAHRENHEIT)

Location	Altitude.	January 9			January 10			January 20			January 21			February		
		Max.	Min.	Range.	Max.	Min.	Range.	Max.	Min.	Range.	Max.	Min.	Range.	Max.	Min.	Range.
	Feet															
Oxford (Hill)	1250	21	4	17	17	−8	25	11	−24	85	21	−10	31	22	−3	25
Brookfield (Val)	1350	24	−3	27	17	−16	33	6	−28	34	21	−17	38	30	−16	44

NOTE.—The rapid rise of the general surface of the eastern plateau brings the valley bottom at Brookfield above the level of Oxford. The distance between the stations is about thirty miles.

The different thermal conditions at hill and valley stations are also shown by tracings of thermographs in Fig. 193.

The nocturnal valley-winds are an important climatic factor, since they bring a cool and refreshing air at night which is not felt on the plains or upper hill slopes. A special study of the subject has been made at Ithaca, in the Cayuga Lake Valley, where it is found that the breeze usually arises from one to two hours after sunset, blowing from the south down the channels of the two principal streams flowing into Cayuga Lake, and gradually gaining a velocity of 10 or 12 miles per hour as the night advances.



Temperature curves at. Mountain
and Valley stations of New York Aug 21st and 22nd 1891
---Temp. at Minnewaska Elevation 1800ft
— " " Port Jervis 470 "

FIG. 193.

Small balloons set adrift at night were often observed to drift northward with this surface current until an altitude of 200 or 300 feet had been reached, when they were caught by the prevailing wind, and abruptly changed their course to the eastward.

We are now prepared to consider in more detail the temperature conditions of the State, as exhibited by the accompanying tables and charts (Figs. 194, 195 and 196).

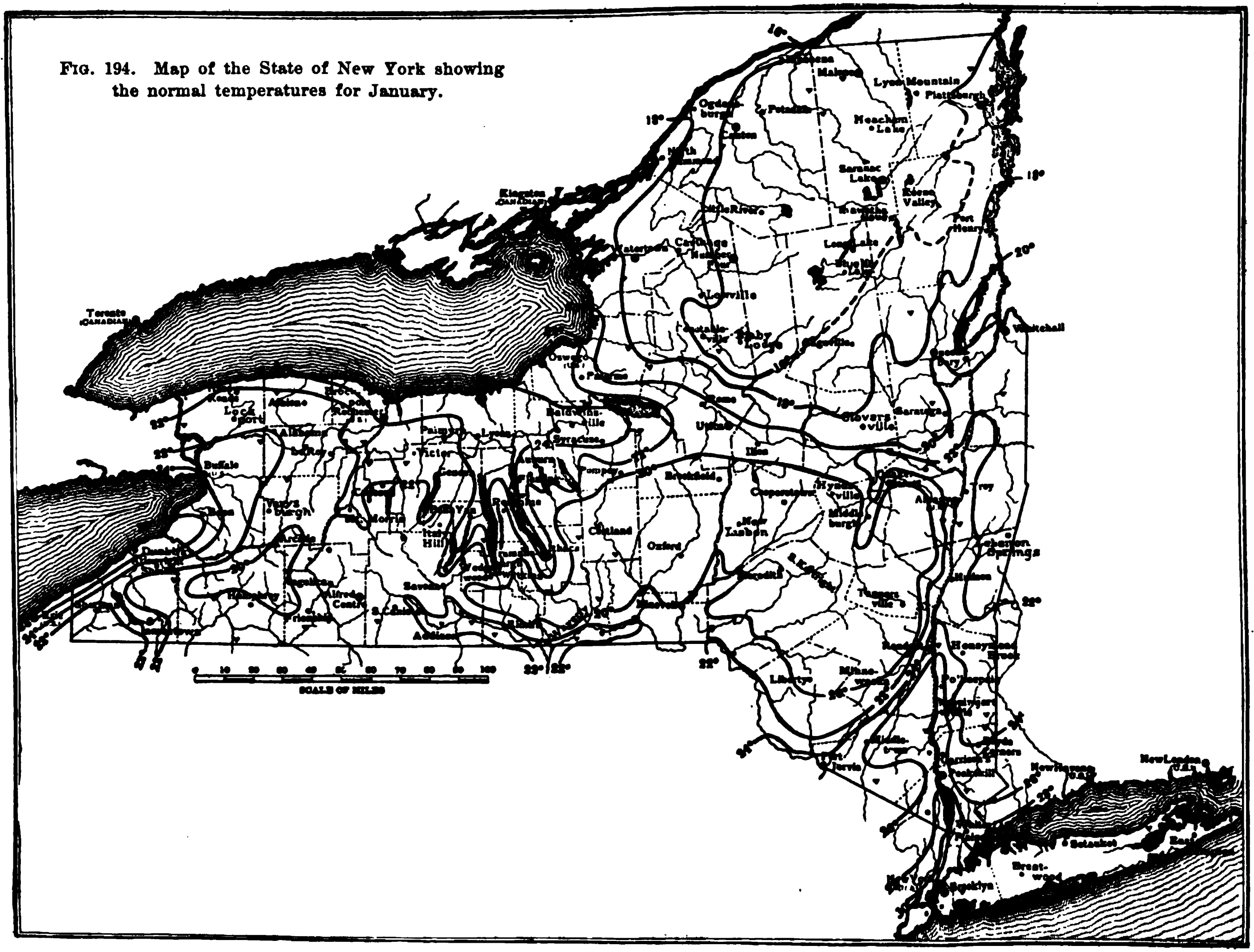


FIG. 194. Map of the State of New York showing the normal temperatures for January.

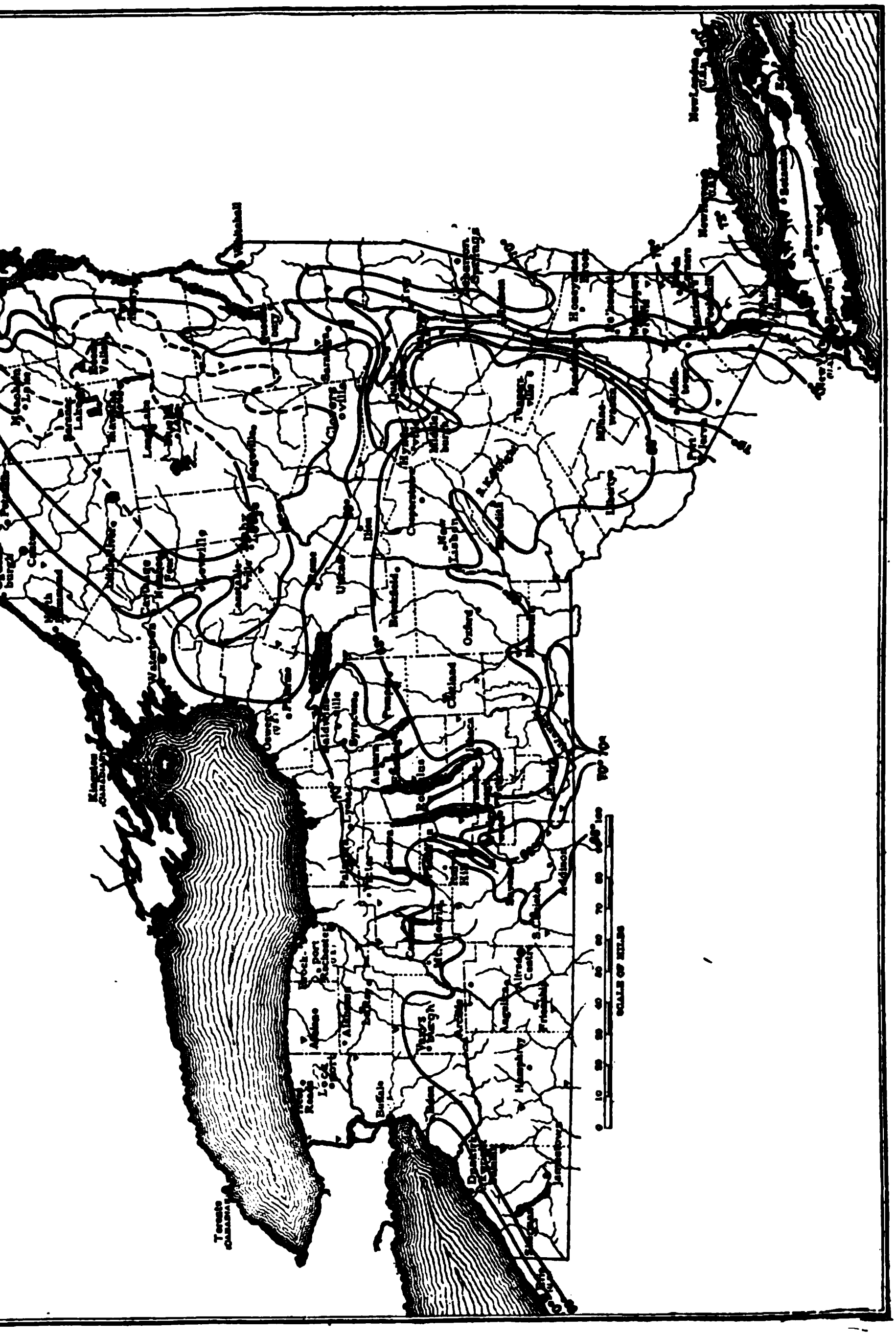


FIG. 195. Map of the State of New York showing the normal temperatures for July.

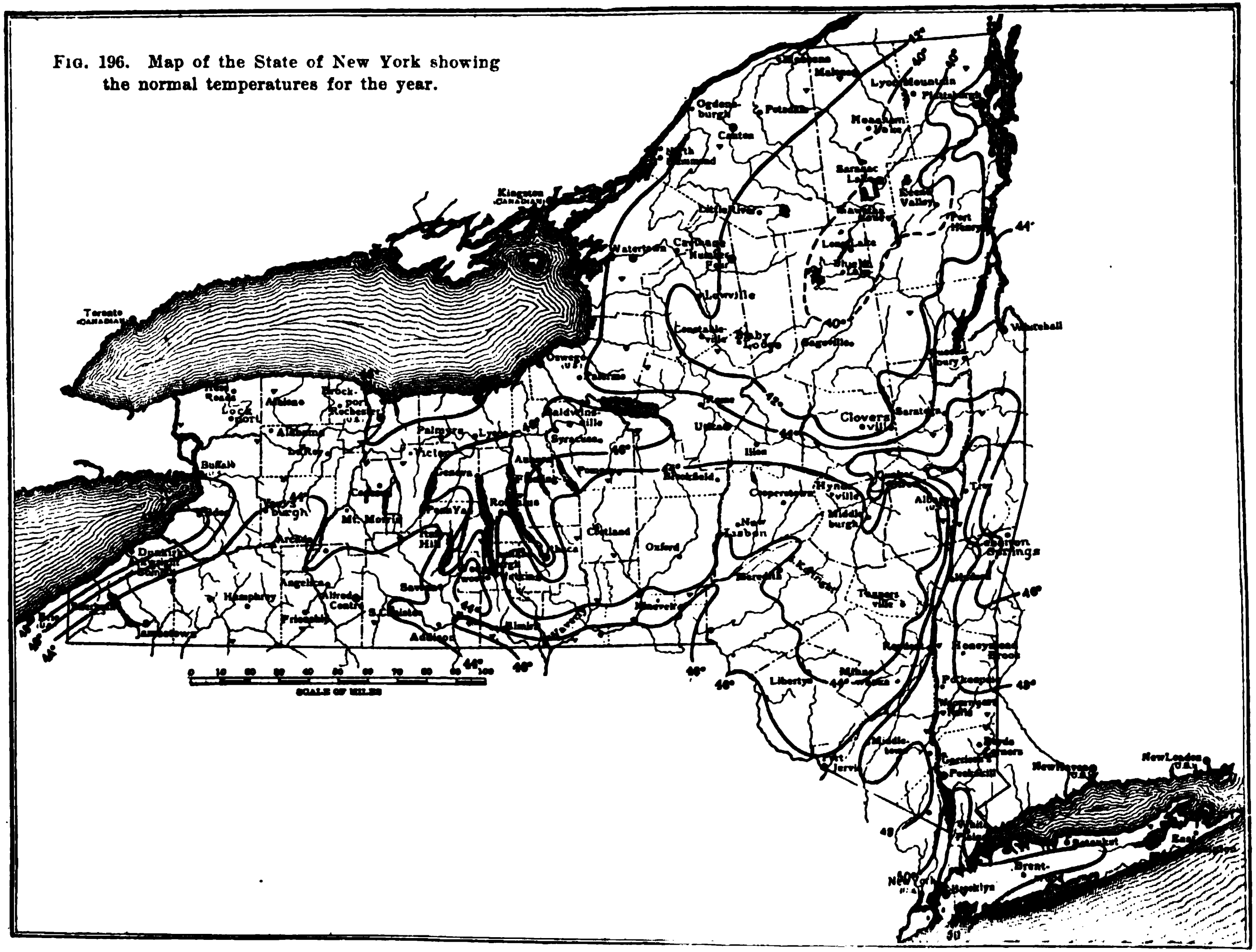


FIG. 196. Map of the State of New York showing the normal temperatures for the year.

TABLE I.—MONTHLY AND ANNUAL TEMPERATURE AVERAGES, DERIVED FROM RECORDS OF TEN YEARS OR MORE

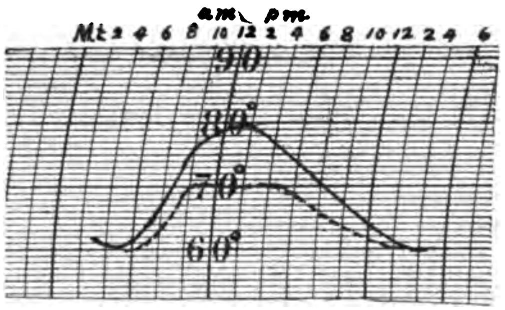
REGION AND STATION	MEAN TEMPERATURE (FAHR.)												
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
ATLANTIC COAST:													
Setauket, L. I.	31	30	36	47	58	67	72	71	65	54	44	36	51.0
New York City	30	31	37	48	60	69	74	72	66	55	44	34	51.7
CENTRAL PLATEAU:													
Cooperstown	20	21	28	41	54	64	68	65	57	46	35	25	43.9
Angelica	22	22	30	43	55	65	68	64	58	46	36	26	44.6
NORTH'N NEW YORK:													
Number Four	17	17	25	39	52	61	64	62	56	44	32	22	41.0
Plattsburg	16	17	26	41	55	65	70	68	58	47	34	22	43.2
GREAT LAKES:													
Buffalo	25	25	31	42	54	65	70	69	62	51	39	30	46.8
Rochester	24	25	31	44	57	66	71	69	62	50	39	30	47.4
HUDSON VALLEY:													
Albany	23	24	32	46	59	69	72	71	63	51	39	29	48.3
ENTIRE STATE:													
(50 stations)	22	23	29	42	56	65	69	67	60	48	36	26	45.4

TABLE II.—EXTREMES OF TEMPERATURE FOR THE YEAR. FROM RECORDS OF THE PAST TEN YEARS

REGION AND STATION	ELEVATION	MINIMUM			MAXIMUM		
		Average for entire period.	Lowest during entire period.	Highest Min. during period.	Average for entire period.	Highest during entire period.	Lowest Max. during period.
COAST:							
Setauket, L. I.	40	+ 4	− 5	+12	95	98	88
New York City	300	+ 2	− 6	+10	95	99	91
HUDSON VALLEY:							
Albany	97	− 9	−16	− 4	96	100	94
CENTRAL PLATEAU:							
New Lisbon	1234	−19	−26	−13	92	94	87
Angelica	1340	−20	−27	−10	92	95	88
NORTHERN NEW YORK:							
Number Four	1571	−25	−31	−17	88	91	85
Canton	300	−27	−43	−15	94	98	90
Potsdam	300						
Plattsburg	180	−18	−25	−12	94	96	90
GREAT LAKES:							
Buffalo	770	− 3	−13	+ 7	90	95	84
Rochester	520	− 4	−10	+ 6	95	99	92

The Atlantic Coast Region.—The nearest approach to a maritime climate to be found within the territory of New York is that of Long Island. The values given for Setauket in Table I indicate a midwinter temperature nearly as high as that for Philadelphia, and 9° above the average for the State, while the midsummer temperature is but 3° above that average. The effect of the ocean and sound in moderating the *daily* ranges, and especially the winter minima, is even more marked, so that the region is very well adapted to the raising and early marketing of tender fruits and vegetables. The first killing frost occurs, near the coast, about the beginning of November, and the last about the middle of April, on an average. Usually, during the winter, the ground is covered with snow for brief periods only.

The *sea breeze* is the most characteristic and important feature of maritime climate in summer. In fair weather the land-wind, which is usually felt at night, ceases soon after sunrise, and the temperature rises rapidly until 9 or 10 o'clock, when the cool breeze from the ocean sets in, gaining strength until early afternoon, when a velocity of 10 or 15 miles per hour may be attained. In general the breeze penetrates inland about ten miles, but on southern Long Island its force and penetration are greatly augmented by the prevailing southerly wind of summer. The accompanying diagram, exhibiting typical hot-weather temperature curves for an inland and coast station, brings out very clearly the moderation of midday heat due to the sea-breeze (Fig. 197).



Temperature as affected By Sea-Breeze.
— Inland Station
---- Sea Coast Station

FIG. 197.

The *Central Plateau*, extending from the Great Lake region on the west to the Hudson Valley on the east, has a more uniform temperature than might be expected to obtain over so large an area since the general rise of the surface toward the south and east largely counterbalances the thermal effects resulting from proximity to the ocean and a more southerly latitude. Hence we may consider the higher levels of this region to be fairly represented by the averages given in the table for Angelica and Cooperstown. The temperature of this section is usually sufficiently low to maintain a continuous covering of ice and snow throughout the winter; but the larger valleys are subject to frequent thaws, which may leave the ground bare for considerable periods. Only hardy fruits can thrive on the highlands, and even in the valleys the temperature commonly falls low enough to damage or even kill peaches.

The midsummer maxima over the plateau average about 4° lower than on the lowlands, and at the summits of the higher hills the midday heat is still more moderate.

The average duration of ice in Otsego and Cazenovia lakes (altitude about 1,200 feet) is from December 15 to April 15. The first killing frost is likely to occur as early as October 1 and the last in May.

Northern New York has a *winter* climate almost as severe as that of the northern interior States, while the summer heat is nearly as great as at equal altitudes in southern New York; and since the region is largely exempt from maritime influences, it is especially liable to sudden and very abrupt changes of temperature. The lakes and forest tracts of the Adirondack mountains have usually a heavy covering of firm snow and ice from the latter part of November until the close of April, so that the air is much drier during that period than in warmer portions of the State. To this fact, together with the presence of large areas of pine woodland, is probably due the favorable effect of the Adirondack climate upon lung diseases, an effect, however, which is shared by the higher regions of southeastern New York.

The minimum temperatures recorded in the St. Lawrence Valley are as low as those of the Adirondack region; in fact the lowest temperature on record for this State (—46°) was observed at the border of the St. Lawrence Valley. There, as in all regions of contiguous mountain and lowland tracts, we may often observe that the temperature actually *increases* with altitude during the progress of a cold wave. This phenomenon, known as *inversion of temperature*, indicates that the cold which accompanies cloudless areas of high barometer is largely a surface phenomenon, due to loss

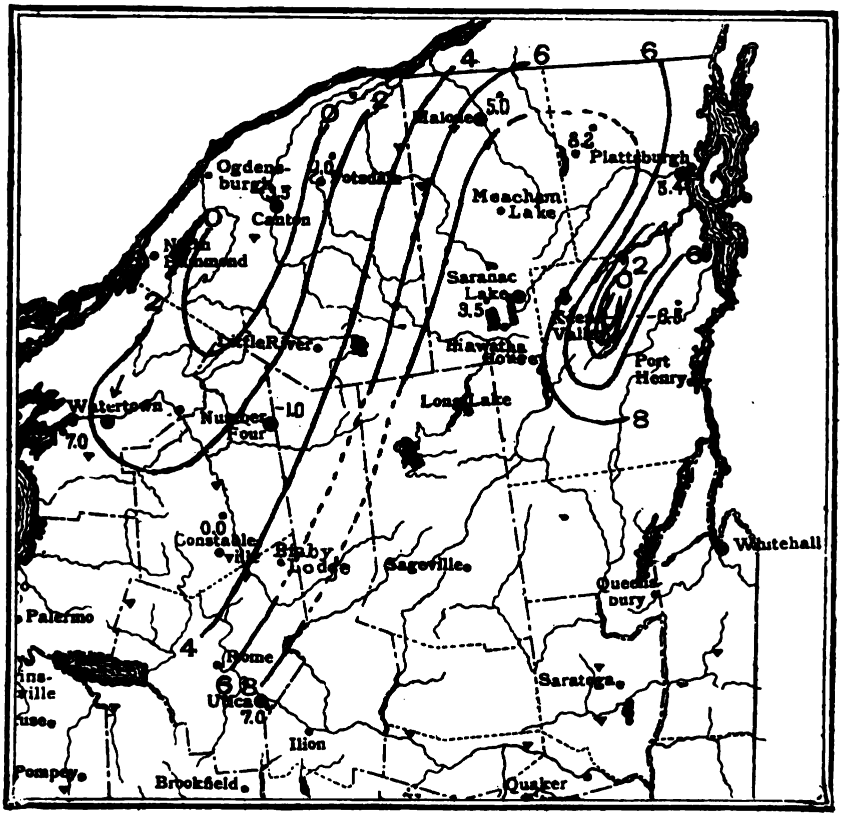


FIG. 198. Inversion of temperature in northern New York, December 8, 1890. Isothermal lines show the mean daily temperature as reduced to sea level by deducting 0.3° from the actual temperature for each 100 feet of elevation. Small figures show actual temperatures. (The mean temperature at Keene Valley was -6.5°.)

of heat from the earth by radiation in the clear dry air that is associated with cold waves. The diagram given herewith (Fig. 198) shows a typical case of inversion, derived from the records of the State Weather Bureau. Had the temperature decreased with altitude at the usual rate, a reduction of the values to sea-level would have given a uniform temperature for the entire region, whereas in this case the isotherm of 0° is found at the lowest levels, and that of 8° in the highest portion of the Adirondacks.

Navigation on the St. Lawrence River is closed by ice, on the average, from about the middle of December until early in April.

The Champlain and Hudson valleys owe their high summer temperature to a sheltered position between mountain walls, as well as to the predominance of southerly winds throughout their extent at that season. The northerly winds of winter, on the other hand, have a clear sweep as far south as the high ridges of the lower Hudson Valley, so that the temperature is often nearly as low as upon the adjacent highlands. The advance of spring, however, is comparatively rapid, especially to the southward of the Mohawk Valley; hence this region is well adapted to the growing of early vegetables and small fruits. The influence of the water of the river, though slight, must also be considered a factor in the adaptation of this region to fruit raising.

The broadest portion of Lake Champlain is commonly frozen over from January to early April. Navigation closes on the Hudson, at Albany, on December 16, and opens on March 20, for the average year.

The Lake Region.—Inspection of Table I and Figs. 194 and 195 shows that the tempering effect of the Great Lakes is most marked in winter, when the prevailing winds must pass over their surface before reaching New York. This effect is clearly brought out by comparing the temperature recorded on the north and south sides of the lakes during the prevalence of a cold wave.

DATE *	NORTH SHORE		SOUTH SHORE	
	Kingston	Toronto	Oswego	Rochester
January 19, 8 A. M.	+ 2	+4	+12	+16
January 19, 8 P. M.	− 6	0	+ 8	+12
January 20, 8 A. M.	−22	−8	− 2	+ 6

* The winds were northerly throughout the observations.

Here Lake Ontario appears to have maintained the temperature at Rochester, from 14° to 28° above the point to which it would otherwise have fallen. The frequent occurrence of conditions similar to the above gives to the southern shore of Lake Ontario an average midwinter temperature 5° higher than that of the northern shore. It thus becomes possible, in our lake district, to raise peaches, grapes and the tender vegetation which can scarcely exist in the adjacent portions of Canada, nor even in the southern interior of the State. The noted grape belt of Chautauqua County, in which over 30,000 acres of that fruit are under cultivation, owes its mild climate both to the proximity of Lake Erie and to the high hills which rise on the eastern side in a semi-oval form. Killing frosts rarely occur in this locality before the close of October; and their latest date in spring is usually previous to May 10.

The eastern portion of Lake Erie is commonly frozen over during a portion of the winter, navigation being closed at Buffalo from early in December to April. Lake Ontario, owing to its greater depth, is less obstructed by ice, and at Oswego the period of navigation is two or three weeks longer than at Buffalo.

A small daily range of temperature obtains at Lake Stations in winter, owing to the almost constant cloudiness of the region as well as to the tempering effect of the water.

The thermal conditions of the Cayuga and Seneca Lake valleys are so similar to those of the Great Lakes that no special treatment of them is necessary. Cayuga Lake is seldom, and Seneca Lake never, frozen over completely. Their immediate shores have an equable temperature, which, with the shelter afforded by the surrounding hills, renders this region a favorable one for fruit culture.

PRECIPITATION

The amounts of annual precipitation in different sections of the State are mainly determined: first, by proximity to various sources of vapor or vapor-laden air-currents; and, secondly, by the character of local topography. In the case of New York State, we may say that, under similar conditions, the precipitation is roughly proportional to the altitude of land-surfaces. This rule does not apply to the central and southern Atlantic States, whose mountain ridges are parallel to the prevailing direction of vapor-bearing winds.

As has been stated, the Atlantic Ocean furnishes the principal vapor supply of the northeastern States. While passing inland with easterly winds the moisture is, in the first place, largely precipitated over the mountains of New England, as is rendered apparent by the extraordinary rainfall on Mount Washington, averaging over 90 inches per annum. A similar condition no doubt exists through the Green Mountain system near the New York border; and hence the lowlands to the westward, including the Champlain and upper Hudson Valleys, receive a somewhat deficient supply as compared with that of the State as a whole. A marked increase of rainfall is again found in the Adirondack highlands, and beyond these a decrease in the St. Lawrence Valley.

Sea-winds from the southeast find no obstruction on the immediate coast of New York; but passing inland they meet the abrupt hill ranges of the southeastern counties, and give to each a copious rainfall as compared with that of the intervening valleys. Liberty, in the mountainous region of Sullivan County, also shows the direct influence of the sea-wind both by its large annual precipi-

FIG. 199. Map of the State of New York showing the average precipitation for the winter.

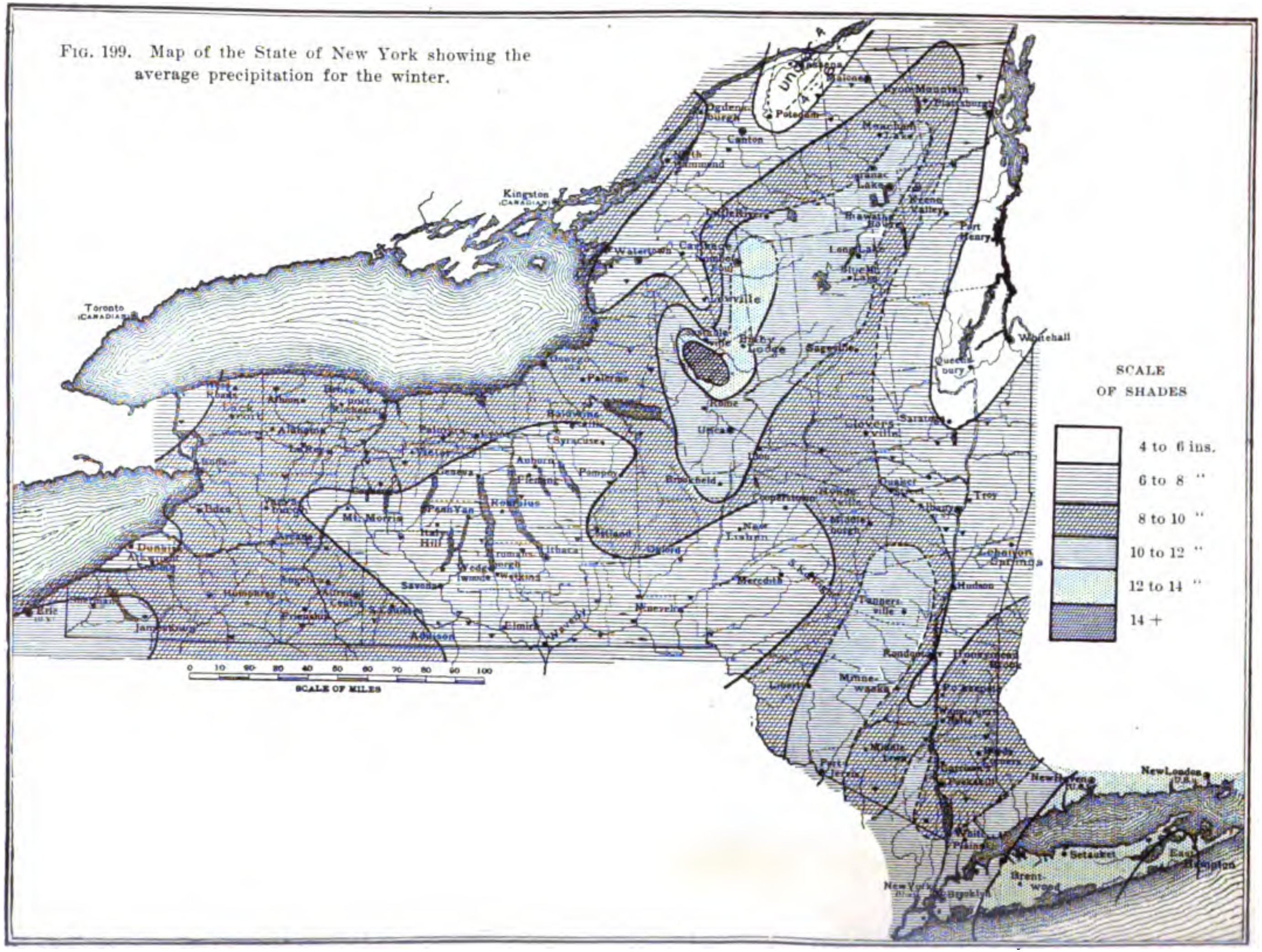
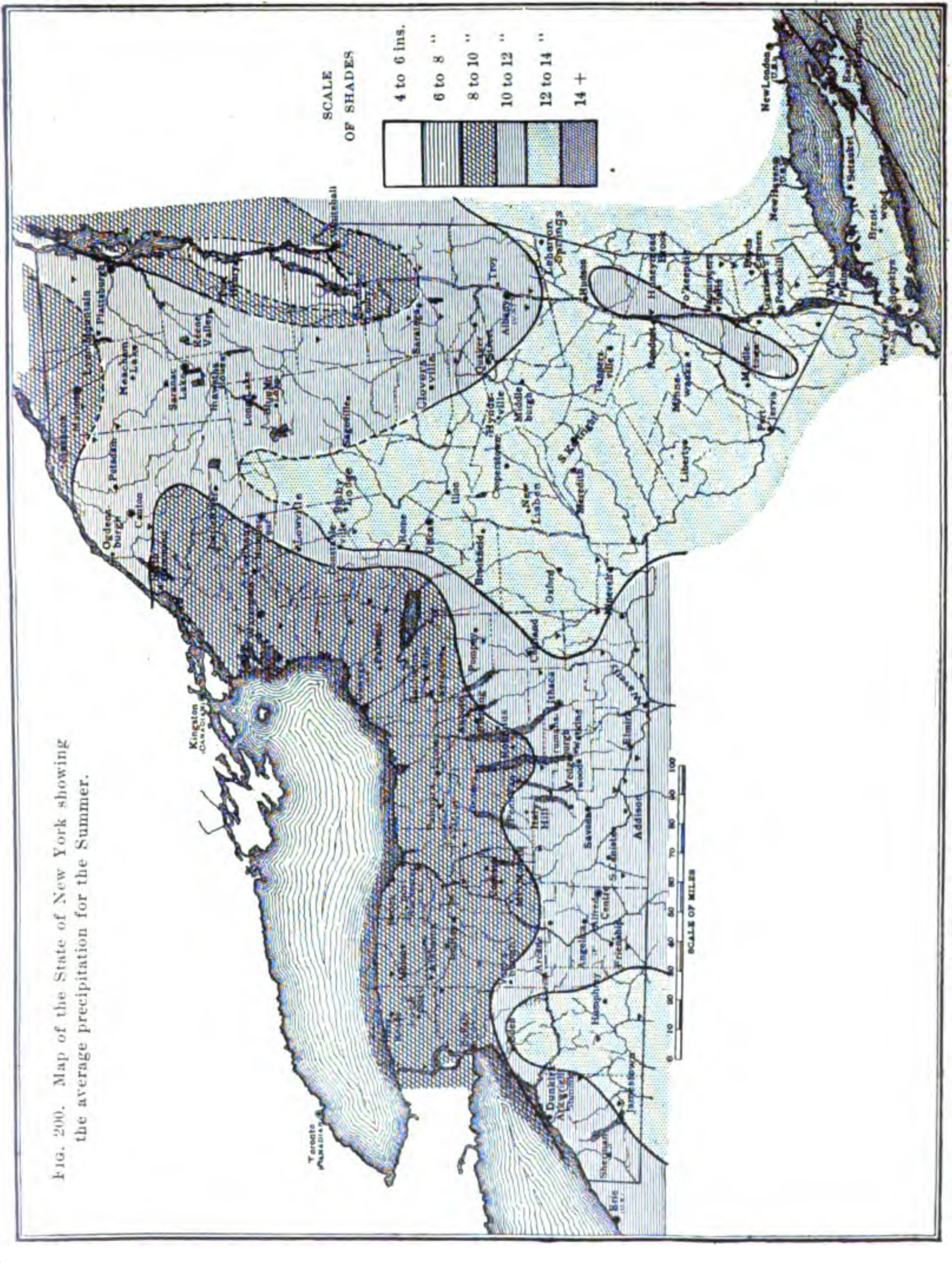


FIG. 200. Map of the State of New York showing the average precipitation for the Summer.



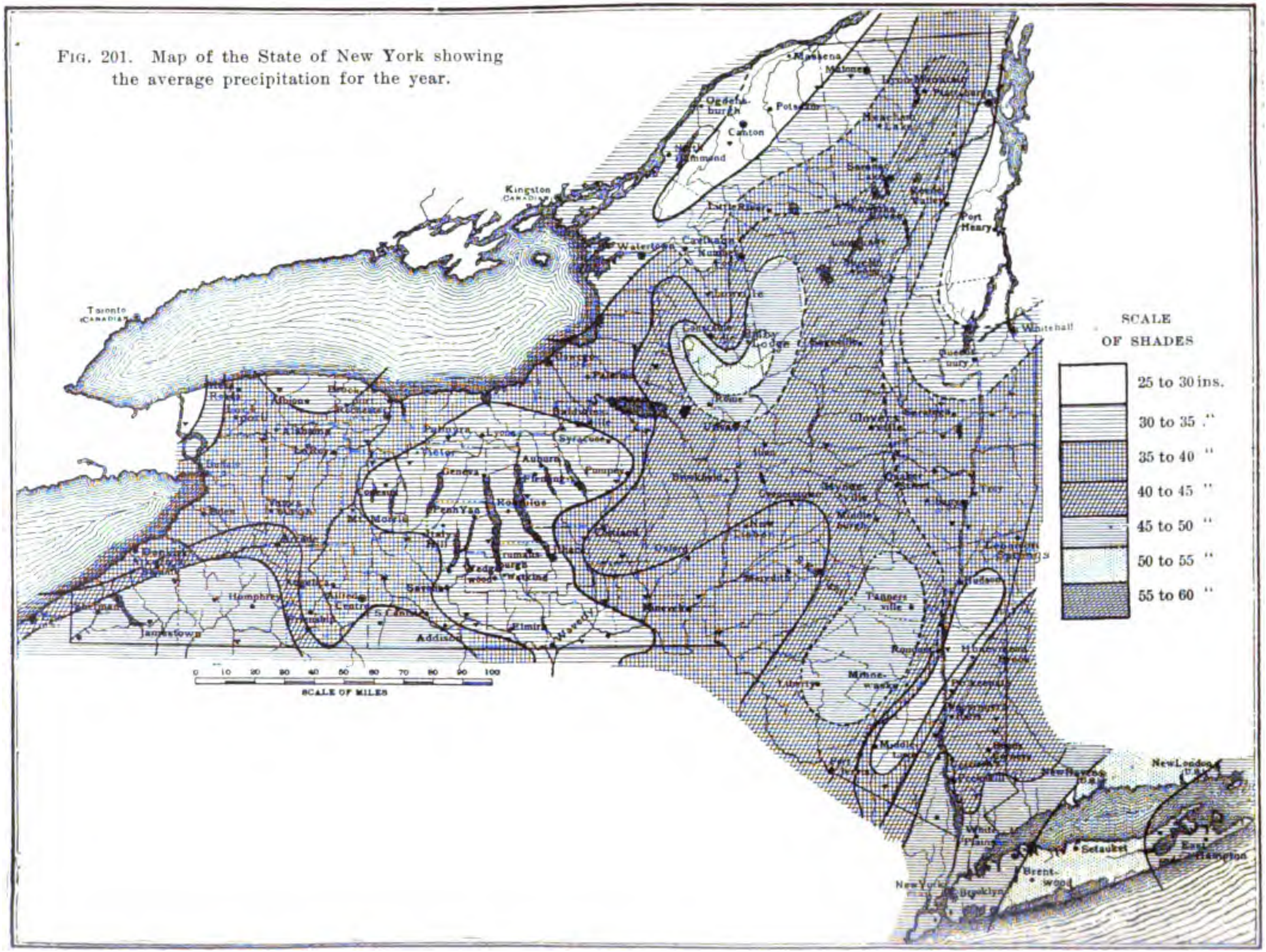


FIG. 201. Map of the State of New York showing the average precipitation for the year.

tation and by a pronounced secondary maximum in winter —a feature not noticed at stations further northward.

Western New York receives an appreciable portion of its vapor supply from the Gulf of Mexico, judging from the frequent southwesterly direction of the rain-winds, and also from similarities existing between the rain types of the Lower Lakes and those of the Gulf and the Mississippi and Ohio Valleys. The total precipitation over the depressed area occupied by the Lakes is rather below the average for the State; but, wherever the surface rises abruptly from their shores, the amount rapidly increases and considerably exceeds that common to equal altitudes in the interior. The winter maximum appears prominently in a large snowfall over the southwestern highlands, and still more so through a section including the hills of Lewis County, the upper Mohawk Valley and an adjacent spur of the eastern highlands in Madison County.

The rainfall in central New York is generally abundant, although somewhat less than that of the southeastern and southwestern highlands. A deficiency, as compared with the average for the State, exists in the principal valleys of the Susquehanna system and also in the depression of the Central Lakes.

Records have not been kept long enough to establish, with accuracy, the amount of rainfall in the central Adirondack region. The brief series of observations obtainable from points near the eastern and western limits of the plateau have been carefully analyzed by comparison of individual monthly values with those of the adjacent stations in the Champlain and St. Lawrence Valleys, the highlands showing a marked excess in all cases. The amounts of rain in the interior, shown by the accompanying charts, were estimated from the data of border stations, somewhat modified by the character of local topography.

MONTHLY AND SEASONAL FLUCTUATIONS OF RAINFALL.— The fluctuations in the average or normal amount of rainfall from month to month do not occur in a uniform manner over the entire area of New York, but must rather be classed

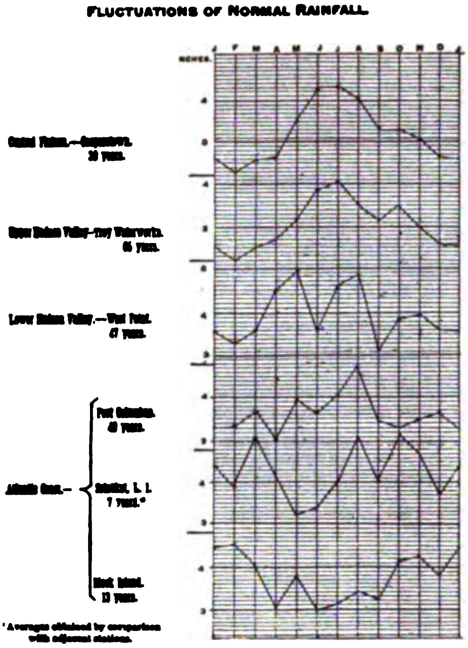


FIG. 202.

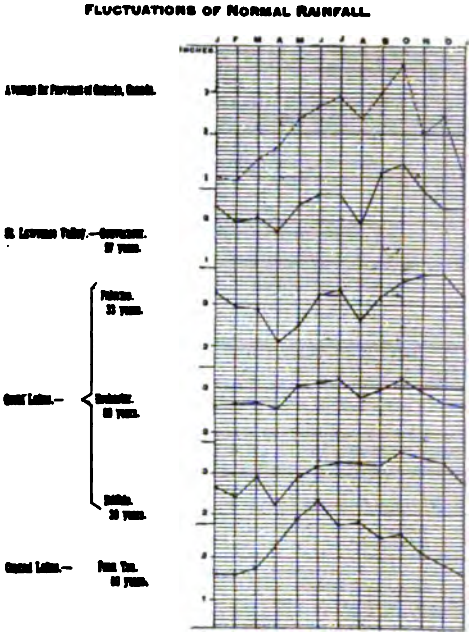


FIG. 203.

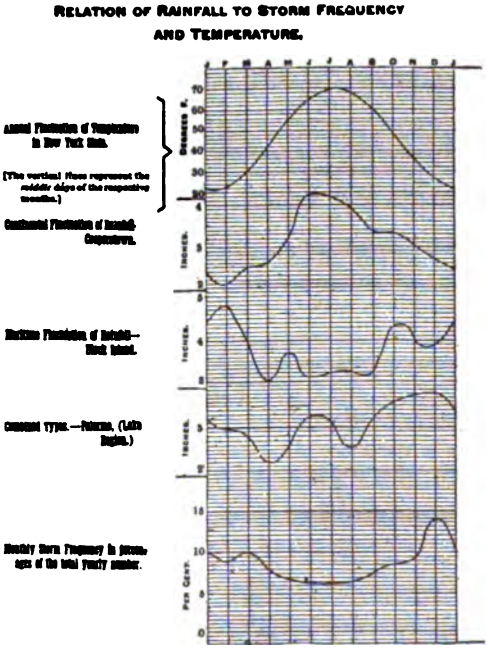


FIG. 204.

under several quite distinct types, depending upon atmospheric conditions, which have already been summarily described. The character of various types and their important modifications are shown in considerable detail by Figures 202, 203 and 204.

A close approach to the continental type of rainfall, with its early summer maximum, is found over the central plateau regions (including the eastern and western plateaus and the southern Adirondack region), as represented by Cooperstown. Proceeding eastward to the central Hudson Valley, a July maximum is found which extends through the Champlain Valley and over the Province of Quebec. In the southern Hudson Valley the maximum varies from July to August, while south of the highlands the maximum occurs in August. This condition also extends over Long Island to Setauket, but disappears at East Hampton and Block Island. The Great Lakes and St. Lawrence Valley show a June or July maximum, which, however, is secondary to that of autumn.

AUTUMN RAINS.—Over the State, generally, a large precipitation obtains in October, as compared with the months immediately preceding and following. This constitutes the principal maximum of the year at several stations of the St. Lawrence Valley, the central part of the Great Lake Region, Central Long Island, and beyond the limits of New York, in New Brunswick, Nova Scotia and Ontario. Within this State an October *minimum* is found only in the vicinity of New York City, but it is a feature common to the coast south of that point, and also obtains at several places in the interior of New England. A relatively light rainfall during September is characteristic of the State at large, whereas in the Upper Lake region the general autumn maximum occurs during that month. Erie, Pa., shows a November maximum, a feature which also prevails in the Ohio Valley.

Over the greater part of the interior of New York the precipitation during the winter is the least of the year. Eastern Long Island, on the contrary, has its annual maximum at that season, while the coast stations generally appear to be about equally subject to continental and maritime influences, showing but slight seasonal variations. This is also true, in even a greater degree, of the region bordering the Lower Lakes, and Rochester may be taken as an example in which an annual fluctuation is almost wholly lacking. Oswego has a principal maximum in June, and a secondary in autumn and early winter; but the latter becomes predominant at Palermo, a few miles to the eastward, and attains a remarkable intensity along the ridge running parallel to the lake in Lewis County.

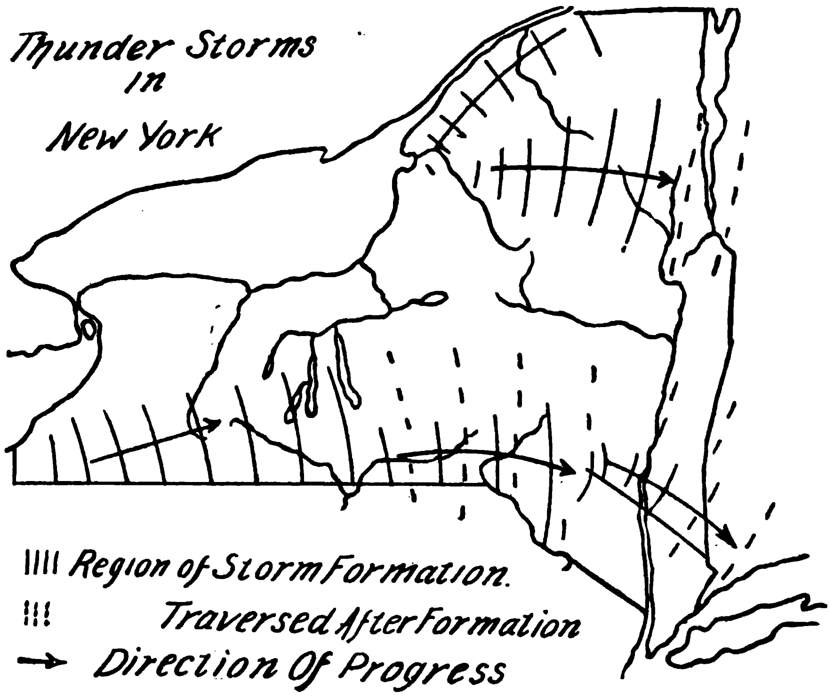

Thunder Storms
in
New York
IIII Region of Storm Formation.
!!! Traversed After Formation
→ Direction Of Progress

FIG. 205.

In the *spring* a March maximum is very pronounced at the Atlantic coast stations, and is also observable inland in a lesser degree. A diminution again occurs in April, after which the curves of the continental type rise towards their summer maximum, corresponding to the change of prevailing winds from northerly to southerly, which occurs in May.

Local Thunderstorms occur almost daily in some portions of the State during the summer months. They form most frequently over the high hills of southern and eastern New York, thence drifting in a general easterly direction, at a rate of about 30 miles per hour, often as far as the coast or over New England. Regions showing a pronounced summer maximum of rainfall, as a rule, owe this feature to frequent thunderstorms.

Fig. 205 indicates the regions in which local thunderstorms most frequently originate, and the directions in which they are most likely to move and spread out. Fig. 206 shows the progress of a thunderstorm of a more general character advancing in front of a large high-pressure area, and preceding a change of weather.

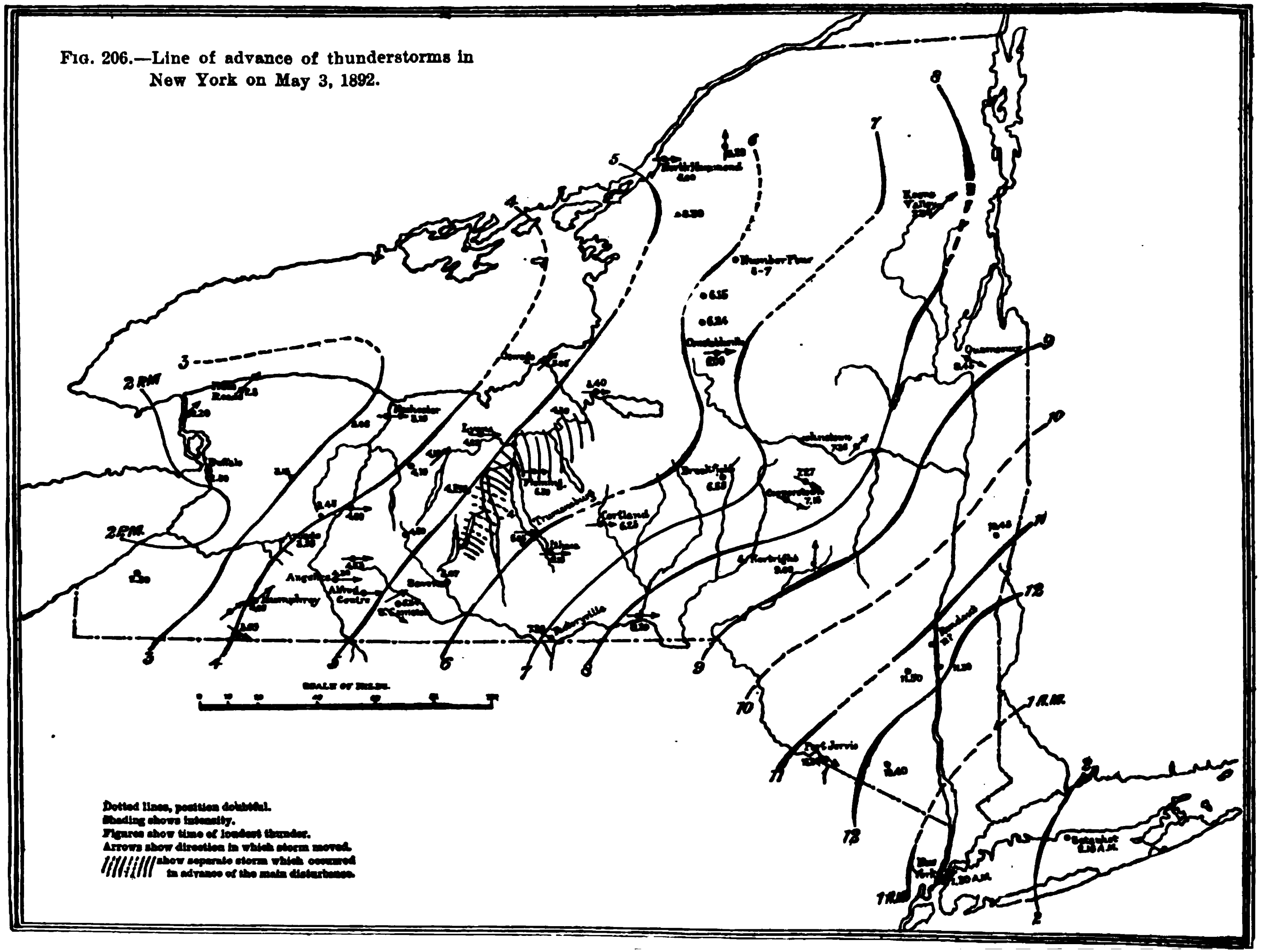
FREQUENCY OF RAINY DAYS

The accompanying table shows the average frequency with which a rain- or snowfall amounting to one one-hundredth of an inch or more occurs, during each month, at six stations in New York and also at Block Island, R. I., and at Erie, Pa., the former station representing, approximately, eastern Long Island and the latter southwestern New York. The rainy days are here expressed in percentages of the total number of days in each month, following the method of the Signal Service charts, from which the values at all stations excepting Ithaca were derived.

PERCENTAGE OF RAINY DAYS.

Stations	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Total annual No.
Block Island, R. I.	47	44	39	35	38	32	36	29	29	35	39	41	135
New York City	39	39	38	37	34	35	36	32	31	31	34	36	131
Albany	45	43	44	40	40	41	39	31	34	35	43	44	146
Oswego	55	49	40	39	37	36	32	26	35	46	56	55	153
Rochester	65	58	57	42	38	39	37	32	38	47	53	61	171
Buffalo	59	55	55	41	39	39	35	31	38	46	55	59	170
Erie, Pa	65	58	57	44	39	41	33	32	41	51	57	65	178
Ithaca	59	54	46	37	46	40	43	37	37	40	46	50	161

FIG. 206.—Line of advance of thunderstorms in New York on May 3, 1892.



Dotted lines, position doubtful.
Shading shows intensity.
Figures show time of loudest thunder.
Arrows show direction in which storm moved.
//////// show separate storm which occurred in advance of the main disturbance.

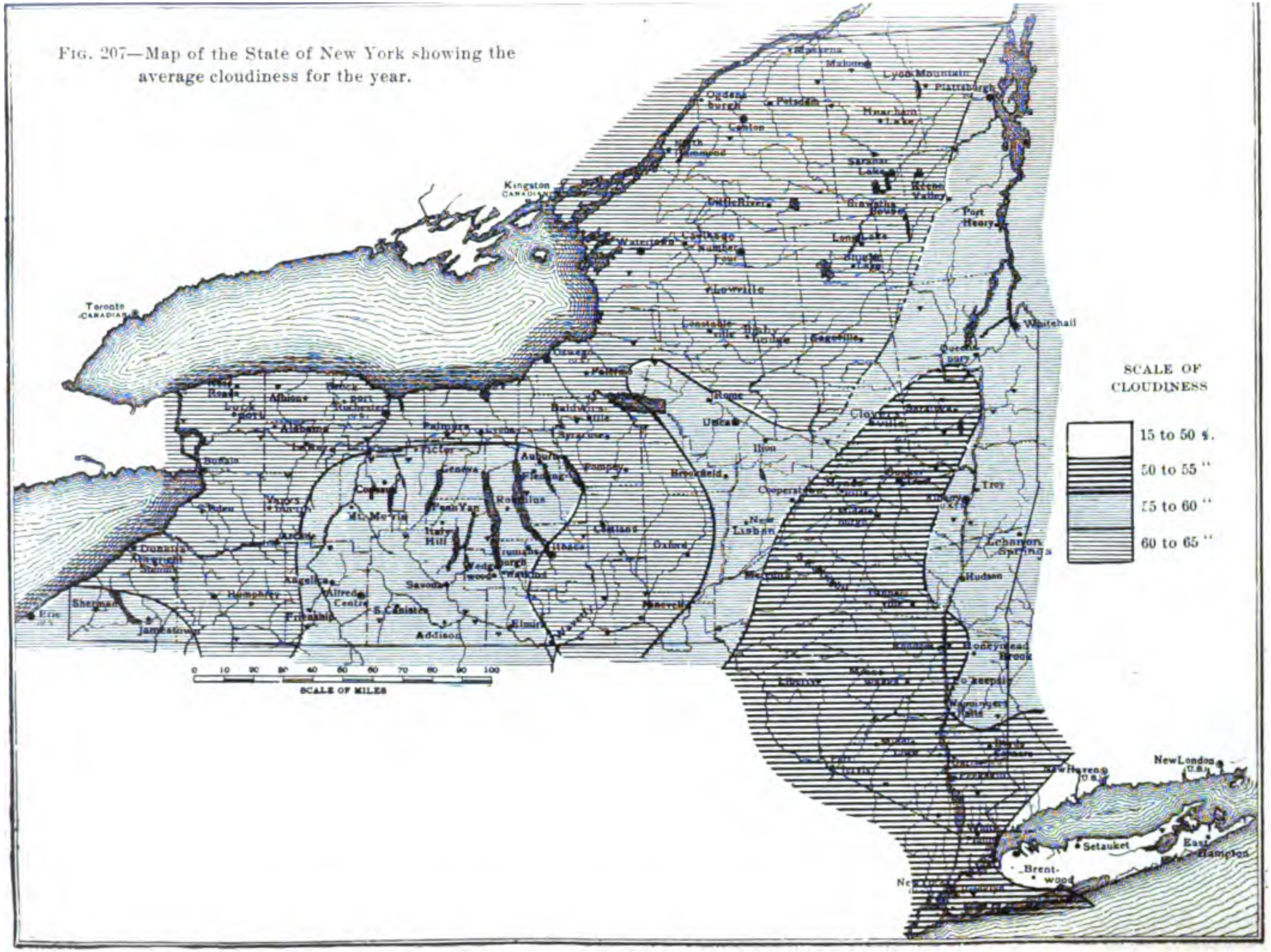


Fig. 207—Map of the State of New York showing the average cloudiness for the year.

Here it will be seen that the frequency of rain- (or snow-) fall is much more uniform over the State in summer than in winter, when the values are about 25 per cent larger near the lakes than on the coast.

The probability of rain for all portions of the State may be fairly estimated from the averages at these stations, although some local variation must be expected, especially in summer, when local rains and thunderstorms are found to be quite unequally distributed over the State. It will be observed that precipitation occurs most frequently during the winter months at all stations, but, making allowance for this general tendency, the number of rainy days is found to follow, in a general way, the fluctuations of the rain curves shown in Figs. 202 and 203, which fact may aid in the estimation of rain probability for various special localities.

PERCENTAGE OF CLOUDINESS. (OVERCAST=100 PER CENT.)

Station.	County.	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Year.
Block Island, R. I.		55	48	51	45	51	40	43	44	47	49	51	56	47.5
New York City	New York	57	51	53	52	51	47	48	47	46	47	51	56	50.5
Liberty	Sullivan	62	62	60	57	49	47	44	45	43	52	66	66	54.0
Albany	Albany	60	57	61	58	52	48	48	50	50	58	60	79	56.0
Burlington, Vt		57	58	64	53	56	44	46	40	51	70	61	72	56.0
Hamilton College	Oneida	76	74	65	56	48	43	38	36	39	57	75	79	57.0
Homer	Cortlandt	76	76	68	61	54	60	47	47	50	61	80	79	63.0
Elmira	Chemung	66	62	54	54	47	52	45	45	51	55	66	66	55.0
Geneva	Ontario	71	69	62	58	48	48	42	41	45	58	70	74	57.0
Oswego	Oswego	81	74	69	56	51	49	47	47	52	65	80	86	63.0
Rochester	Monroe	80	70	69	56	50	48	45	44	49	60	77	83	61.0
Buffalo	Erie	77	66	64	56	52	48	48	44	50	60	74	81	62.4
Erie, Pa		77	66	64	55	52	48	48	44	50	60	74	81	62.4

For our present purposes, the sources of cloud-formation may be included under two heads: First, low pressure or storm areas, and second, local sources.

Low barometer areas usually bring with them a heavy cloud-layer, many hundred of miles in extent, and since such disturbances pass in the vicinity of New York at intervals of three or four days during the winter, a large percentage of cloudy weather must be expected at that season, especially in northern and western New York, which sections lie nearer to the common track of storm centers than does the coast region. The lesser extent and frequency of low barometer areas during the summer months account in a large measure for the increased sunshine which then obtains.

The Great Lakes are the most important source of the *local* clouds in winter. The vast quantities of vapor which rise from the lake surfaces are condensed by the prevailing cold northwesterly winds, and drift with them in a broad sheet over the greater part of western and central New York. Southeastern New York owes its clearer atmosphere to the fact that the prevailing winds carry the ocean vapors *away* from, and not toward, the coast.

In summer the prevailing southerly winds carry the lake vapors over Canada rather than New York, and also the high air temperature to a large degree prevents condensation and cloud-formation. Hence, during the warm months fair weather prevails much more uniformly over the State than in winter.

The distribution of cloudiness over the State for the year is shown by the accompanying chart (Fig. 207).

RELATIVE HUMIDITY. (PER CENT.)

STATION	Jan.	Feb.	March.	April.	May.	June.	July.	August.	Sept.	Oct.	Nov.	Dec.	Year.
Block Island, R. I	76	78	75	76	83	83	82	82	82	79	78	79	79
New York City	74	73	68	65	66	69	71	72	72	70	70	73	70
Oswego	74	74	73	68	67	70	71	71	71	71	71	76	71
Albany	75	74	71	63	62	66	67	68	72	72	74	76	70
Rochester	80	77	76	67	64	67	68	68	70	72	76	80	72
Buffalo	80	78	75	71	68	71	72	71	72	73	76	79	74
Erie, Pa	79	78	76	70	66	70	70	70	72	72	75	79	73

Although the *absolute* amount of moisture in the air is least during the winter, the percentage *relatively* to *saturation* (the relative humidity) is then generally at a maximum. At Block Island, however, the northerly winter winds have traversed a lesser expanse of water surface than the southerly or ocean winds of summer, and this circumstance, with the more moderate degrees of heat and cold to which the island is subject, reverses the rule applying to inland stations, causing the maximum humidity to occur during the summer. This is the case also along the south shore of New England and probably over the greater part of Long Island.

The maximum humidity at the Weather Bureau Stations within the State is found at Buffalo, which is subject to prevailing winds from the Lake. The region of least moisture, on the other hand, appears to be the Champlain Valley, as shown by a two years' record at Plattsburg. The conditions are here very dissimilar to those of stations at the same latitude in the St. Lawrence Valley, the latter region showing substantially the same humidity which prevails near the Great Lakes.

The limits of this paper have rendered it necessary to consider climate as a fixed and definite entity, whose elements are represented by the averages of long series of observations. As a matter of fact, successive years may differ so widely in many or all of their characteristics as to bear little resemblance to the ideal which our averages represent. For example, the highest mean temperature on the records of New York City for January was 40°, which is the *normal* value for that month at Norfolk, Va.; while the coldest January at New York has the same average as the normal at Portland, Me. (20°). The fluctuations of other elements are quite as marked. Rainfall is especially variable, the annual total at Ithaca in one case, for instance, differing from the normal by 50 per cent.

To determine the extent and law of such fluctuations, an examination has been made of the records, which, in this State, extend back to 1826. As regards temperature, it is found that the coldest months of the year are the most variable, and that the variation may amount to 10° either above or below the normal, giving a range of 20°; but has not, so far, much exceeded that amount. In summer, the range of monthly means does not exceed 12°. We also find that deviations of 2° or 3° on either side of the normal occur about as frequently as a closer agreement with the normal; but beyond that limit warm or cold months are less frequent in proportion to their deviation from the normal. The normal has, then, a meaning and value as being approximately the ***most probable value.***

The same rule holds in a measure also for precipitation; but the variations of this element are so wide that the formulation of any law becomes hazardous, and certainly is beyond the scope of this article. The rainfall in a single day may exceed that of an entire season, and, as already stated, the annual totals are subject to variations of over 50 per cent. If, however, we compute the total precipitation of the Januarys (say) of a long series ot years at a given station, and then for a second period of like duration, the two will agree quite closely, and the more so as the length of the periods is increased.

The normals (which are simply these totals divided by the number of years of the record) thus serve an important purpose in bringing out the ***characteristic*** fluctuations of rainfall from month to month, and in different regions.

It is often asked, *Is our climate gradually changing?* To this question no perfectly definite and satisfactory answer can as yet be given; but we may at least assert that the changes, if any exist, are not sufficiently important to be readily discernible in the long records at our disposal. Only the broadest survey of climatological evidence can justify any conclusions in this matter, and for such a survey we must look to the work of Brückner in Germany.[1] This investigator has made use of all available records of weather, ice-formation and fluctuations of level in rivers and lakes, dates of harvest and other historical material, for the entire northern hemisphere. He concludes that relatively warm and dry periods alternate with cold and wet periods; the same phases recurring at intervals of about 35 years, or more accurately, as follows:

WARM AND DRY.	COLD AND WET.
1791-1805	1806-1820
1821-1833	1836-1850
1851-1870	1871-1885
(1886-1905)	....

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[1] See Modern Meteorology, by F. Waldo, Scribners.

The cold years differ from the warm years by about 2°; and the dry years from the wet by about 20 per cent of the total precipitation. These results have little value, however, excepting in their scientific aspect; for they show wide deviations from the data of a restricted region like our own, and furnish but little basis for local predictions. The progress of deforestation is also often said to be the cause of important changes in climate; but the most careful investigation of the subject has hitherto given only negative results.

CHAPTER XII

INFLUENCE OF PHYSIOGRAPHIC FEATURES UPON THE INDUSTRIAL DEVELOPMENTS OF THE STATE

MOUNTAIN SCENERY.—There are few places in the word in which the environment—climatic and topographic—have not produced an important influence upon human progress. But one would need to look far and wide to find a better illustration of this than is offered by the State of New York. In the main the State consists of a series of plains and much-dissected plateaus, comprised generally of broad valleys and rounded hill-slopes. Semi-mountainous here and there, the surface becomes truly so in two parts only—the Adirondacks and the neighborhood of the Catskills.

These mountains—rugged and rocky—are sparsely settled districts in an otherwise populous State. The unfavorable conditions of soil and topography for a long time discouraged settlement; but recently, on account of the more widespread development of the æsthetic sense, those who have leisure have sought these districts because of their varied and picturesque scenery and because of the lower summer temperature which results from their elevation.

The picturesqueness of these mountain districts is partly due to their elevation, as a result of which they have been carved into varied outlines, and partly to the effects of the glacier which has spread over practically the entire State. Moving slowly and irresistibly over the land, the great ice-sheet scoured the hilltops and dragged its load of boulder-clay into the valleys, clogging them here and there, and sometimes transforming them into lakes, sometimes causing the streams to choose new courses, along which they have since dug their channels, carving gorges in the rocks and leaping from layer to layer in cascades, rapids and falls.

Thus, by the effect of glaciation, a new beauty has been added to a region already picturesque.

THE LUMBERING INDUSTRY.—In working upon the hard rocks of the mountains the glacier has swept off the soil that previously existed, and over large areas has left in its place either bare ledges or a boulder-strewn surface. Neither is the slope too great nor the climate too rigorous for successful agriculture in most of this mountainous tract; but as a result of the glacial accident the soil is either poor or entirely lacking. Much the same is true concerning the higher hills of the plateau region in southern New York. It has, therefore, not been worth the while to clear off the forests, as has been done elsewhere, so that the hilltops and mountain slopes are still wooded, furnishing a forest reserve long after one would have existed in a more level region. In this respect the Adirondacks and the Catskills resemble northern New England rather than the remainder of New York.

Lumbering, as an industry, is one of the few occupations that are available for those who dwell among these mountains, for minerals are few and mostly of little value, while building-stones, which might be of use, are too remote from market. Removal of the forests has proceeded so far that little of the primitive growth remains, and even though large sections of the Adirondacks are inaccessible, except on foot, the lumbering operations have extended over nearly all their slopes. This has been rendered possible here, as in Maine, partly by reason of the climate, and partly, once more, by reason of the influence of the glacial period. The cold winter freezes the ponds, swamps and streams, and permits heavy snowfall, which levels the surface, burying the dead logs and boulders, thus permitting sledging in the winter, so that supplies may be drawn into the lumber camps and the logs be hauled out from the woods. The heavy snows of the mountains supply the necessary spring torrents by which the logs are drifted down to sawmills.

The effect of the glacial period upon the lumbering industry, in addition to its effect upon the soil, is primarily in the formation of lakes, which act as storage reservoirs for the water supply needed by the lumbermen who are driving their logs down stream. Thus a region unfitted for the dense population of an agricultural district is sparsely occupied by those whose business is lumbering. A road map of New York State shows a remarkable blank in the hilly districts of the plateau of Cattaraugus County, the Catskills and the Adirondacks (Fig. 208).

The lumbering industry of the mountain districts has naturally had a distinct influence upon the industries of the sections round about. Where hemlock bark is easily accessible, tanneries, and leather work in general, have been possible. Sawmills, lumber mills, paper mills and other industries using timber have also naturally developed near by.

THE AGRICULTURAL INDUSTRY.—The glacial accident has stamped its effects upon the entire State. No doubt before the ice came there was a residual soil caused by rock decay and not unlike that now covering the surface in the more southern states; and no doubt this same kind of soil covered all of New England. This soil was almost entirely swept away, and in its place was set down the present glacial soil, consisting for the most part of a mixture of clay and boulders, here and there of poor quality, but in general strong and favorable to agricultural pursuits.

One unacquainted with the explanation, but knowing well the New England and New York region, would scarcely recognize in the two contrasted kinds of soils a single product of ice action. In New England the surface is often so boulder-strewn that it at times seems a wonder that any agriculture should ever have been attempted there; but in New York, outside of the mountainous eastern section, there are so few boulders upon the surface that one rarely sees a stone wall—one of the characteristic features of much of the New England scenery. This difference is due to the kind of rock which the ice found to carry. In New England it bore granite and other hard fragments; in New York, usually softer shales and limestone. Crystalline rocks were sup-

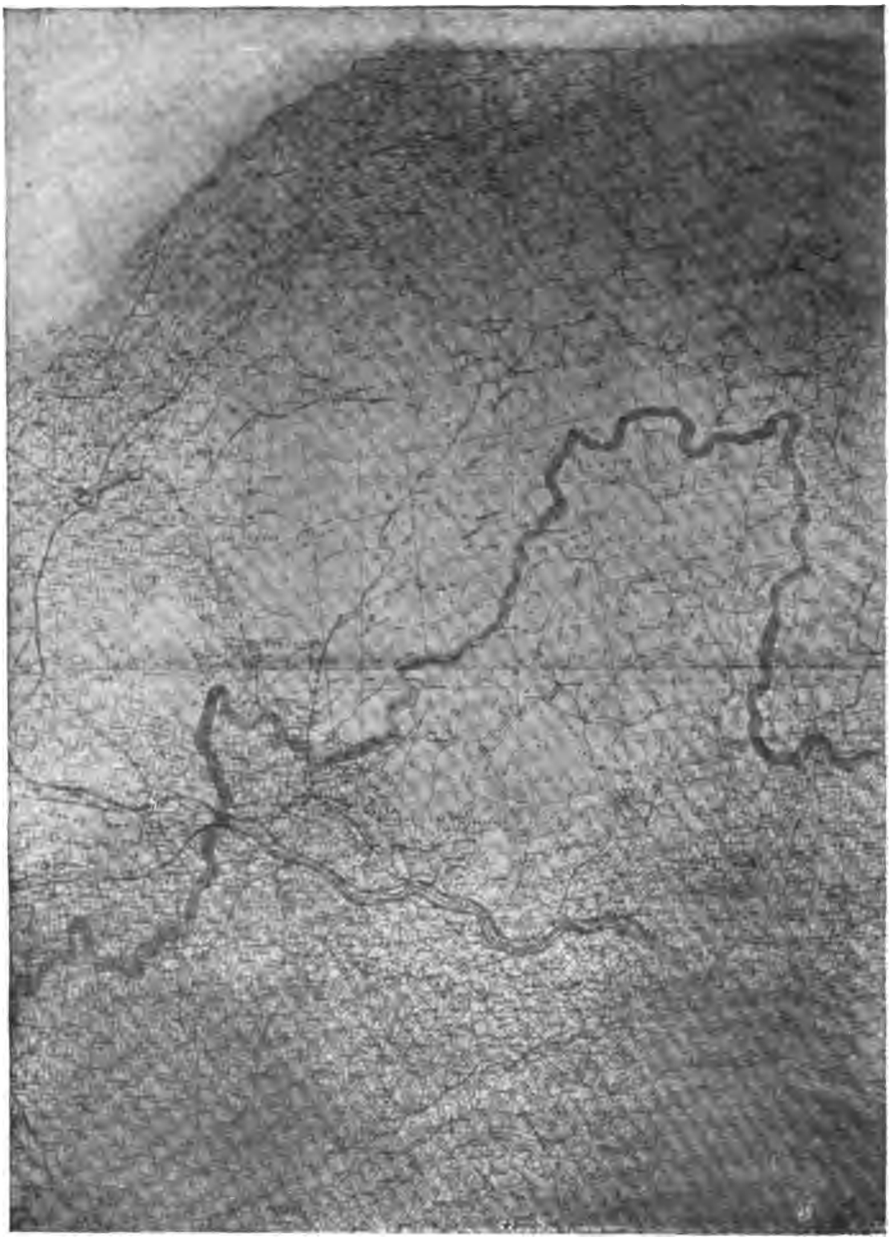

Fig. 208. Road map of the Adirondacks and vicinity, showing the scarcity of roads in the timber-covered mountainous sections.

plied to New York from Canada, it is true; but in their long journey these were generally ground to clay, though here and there "hard heads," which have escaped comminution, may still be seen on the surface. In the neighborhood of the Adirondacks, and other sections where the rocks are hard, the glacial soil closely resembles that of New England.

This soil of glacial origin varies greatly from place to place, so that innumerable minor influences of physiography upon occupations are found. There are glacial plains of compact clay soil that produce crops of apples and pears; there are very extensive beaches of gravel,—the seats of vineyards; there are thin soils, suitable only for pasturage; and there are sandy stretches of little value to the agriculturist. Some sections are smooth and regular; others are so hummocky that farming must almost be done by hand; and some portions of a single farm are level, others irregular, some with good soil, others with poor. It is along the terminal moraine that the most marked irregularities of this sort are found.

The rounded preglacial topography was rendered even less irregular by the ice visit. Hills were lowered by ice-scouring and valleys were partly filled with the debris. Therefore, since it left a good soil, the glacier, by smoothing the surface somewhat, made the greater part of the State better adapted to the immense and varied agricultural interests which have developed than it was before the glacial period.

Under conditions of variable soil and irregularity of topography an exceedingly varied agricultural industry has arisen in the State. It has not depended entirely upon the soil, but in part upon the climate and in part upon the needs of the people, developed through the creation of industries of other kinds than agriculture. The influence of climate, for instance, is well illustrated by the important fruit-belts along the shores of lakes Erie, Ontario, Keuka, Seneca and Cayuga, and also along the broad estuary of the Hudson River. The influence arising from the demands of people who are engaged in other industries is illustrated in the neighborhood of each of the cities of the State, where many men are engaged in raising crops almost exclusively for consumption in the cities.

But while these other influences must be considered, the most directly important controlling force in the agricultural development of the State is undoubtedly the soil itself. The glacial soil is strong, and will stand a great deal of unwise culture, although in time even the best becomes exhausted if too heavy a drain is made upon it. Soils of residual origin have been caused by the decay of rocks, during which most of the soluble material has been leached out, although enough is still stored up to supply plants with the necessary food, and do it so readily that at first wonderfully rich crops are produced; but ere long this abundance of plant-food is exhausted and the soil is run down, and has its fertility restored only with great difficulty. This is very clearly illustrated in the overworked and abandoned plantations of the South.

A glacial soil, on the other hand, being composed of rock fragments scoured from the ledges and by the grinding of boulders together, consists of many undecayed, or only partially decayed, rock fragments. These, under the action of frost, or the effect of roots of plants and other agents of rock decay, are slowly furnishing to the glacial soils the very plant-food that the vegetation needs. There is, therefore, a steady supply of the elements of fertility, although not quite rapidly enough to counteract the heavy drain made by over-tillage. The glacial soil is not a mere storehouse of plant-food, but a manufactory of it as well; and glacial soils are therefore so strong that they last for a long time.

THE BEGINNINGS OF MANUFACTURING.—A great agricultural industry, particularly one so varied and specialized as that of New York State, could not have developed unless a market were found for its products. The farmer may supply himself amd family with food, and in a crude way may live and have the necessities of life even when entirely isolated, but he cannot go farther than this unless he is able to find some one who needs a part of his products and is willing to exchange for them something which the farmer himself needs. The pioneer settlers, of course, did not have this coöperation, but, just as now there are farmers living in portions of the Far West in practical independence of other people, so then the pioneers were dependent entirely upon their own energies and ingenuity to supply their pressing needs.

There are two natural means by which the products of the soil may be made of value in exchange, and, fortunately, New York possesses both of these, and the pioneers early developed them. If the natural facilities favor the development of other industries than agriculture, those engaged in these industries will need to be fed by the farmers; or, if the people in more distant sections may be easily reached, the crops from the farms may be shipped away in exchange for other products.

From the very earliest settlement of the State other industries than farming have been in existence. At first there was trapping and hunting—a form of industry which supports but a limited population, and that of an unsettled kind, roaming about from place to place. The hunter and trapper are practically as independent of all other people as is the farmer in remote regions, but the hunter is, nevertheless, able and willing to exchange products of the chase for the materials raised on the farm. While the trapper comes first in the settlement of a forested region, the woodchopper usually succeeds him, sometimes destroying the timber for the purpose of clearing a patch of land for his crops, but often engaging in the business in an extensive way, clearing off trees and removing the logs (Fig. 209). In a region of good soil the lumberman is naturally quickly succeeded by the farmer; so in the early days of the development of the State, after the trapper came the lumberman, whose occupation, not being a food-supplying one, demanded that he should be supplied with what he needed for food and clothing. As little patches of meadow land among

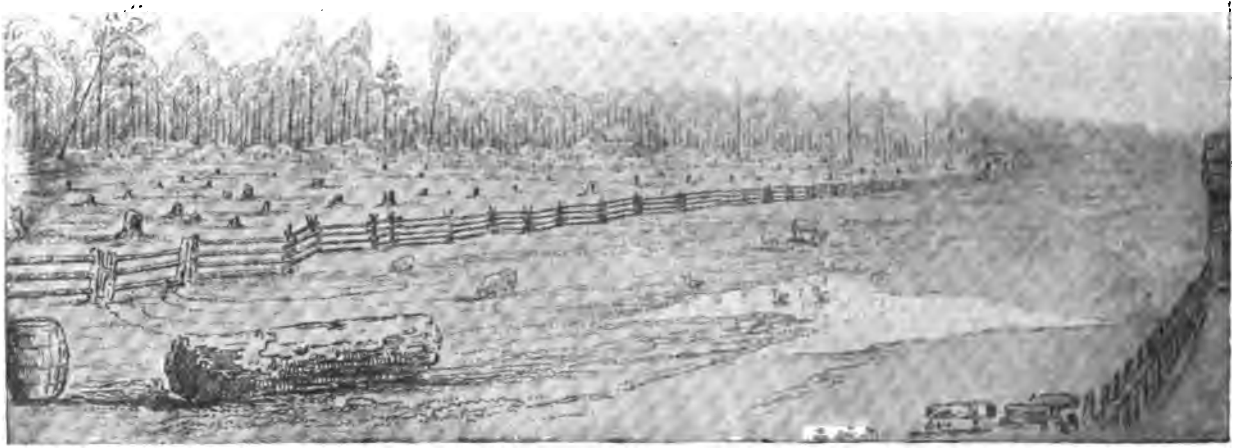

Fig. 209. Field of tree stumps — a scene in western New York in 1832.

the woods of Maine, far away from the railways, now supply their owners with an excellent living because of the crops of hay, potatoes, etc., which they produce for the lumbermen, so in the early days of New York history, one of the sources of profit to the pioneer farmer came from the demands that were made upon him by the lumbermen.

Timber-cutting means not merely the work of cutting the trees and floating the logs away, which would supply employment to but a limited number—it demands that there shall also be much work in preparing the lumber for market. As to-day the lumber where it stands in the Adirondacks, or in that immediate neighborhood, is of very little value because of the absence of market, so while the forests in the agricultural part of the State were being stripped off, it was necessary not merely to cut the trees but to remove the lumber. As now in the Adirondacks, so then in the remainder of the State the removal of the forests was greatly facilitated by the waterways. Lumber could be floated down the streams and was removed in that way, and this fact has had a great influence upon the State, being of importance not merely because it served as a means for the removal of the forests, but also because it furnished one of the first great proofs of the importance of these waterways.

Therefore, early lumbering was an industry serving not only to employ the men immediately engaged in it—in cutting the trees, floating the logs and sawing them up—but also aiding agriculture partly by clearing off the forests which encumbered the land, and partly by furnishing some support to the growing industry of agriculture through demand for the farm products. It furthermore aided in the industrial development of the State by pointing out the usefulness of the waterways, whose later development has had such notable influence upon the prosperity of the entire State.

The necessity of making the rough logs into lumber and wooden articles, as barrels, laths, shingles, etc., caused the location of sawmills in various parts of the State. This work of transforming the rough lumber to various wooden articles was greatly facilitated by the numerous rapids and waterfalls scattered over the State as a result of the glacial accident which has turned so many streams from their courses and forced them, in choosing new courses, to tumble noisily along over the rock layers of variable hardness. Most of these sawmills have now disappeared, and their water-power has come to be utilized for other purposes, so that one traveling over the State at the present time would scarcely realize what an important step in the industrial development of New York this removal and manufacturing of lumber has been. It was the basis for the wealth of many of the families of New York State. Turning their attention to the removal of the forests from the land, they developed a capacity for this form of business which, when the opportunity disappeared through the removal of the timber, was transferred to other regions, even though the man himself remained living where he first began his lumbering operations. Some of the lumbermen worked toward the Adirondacks, others saw still greater opportunities in the West, and much of the development of lumbering in the Michigan and Wisconsin region has depended upon the skill previously acquired in New York State. Now that these western forests are disappearing, one finds the Wisconsin lumbermen transferring their business interests to other fields, as, for instance the South. One of the important results of this ancient lumber industry is found in the location and development of Cornell University, which owes much of its financial endowment to the lumberman's skill and business foresight.

Closely succeeding, and in many cases even accompanying the manufacturing which was associated with the removal of the forests, came the development of manufacturing associated with agriculture. And since agriculture has permanently succeeded lumbering in most parts of the State, the grist-mills, which were the first of the manufacturing plants related to the agricultural industry, have maintained their hold and are still in operation along the hundreds of creeks which flow with torrential course down their post-glacial valleys.

THE LATER DEVELOPMENT OF MANUFACTURING.—Many other forms of manufacturing have developed as the State has become more settled. The grist-mills near the waterfalls of the Genesee at Rochester have developed greatly in importance, and the water-power is utilized for many other forms of manufacturing. The demand of the agriculturist for implements has led to the development of the immense Osborne plant at Auburn. Cheese factories and creameries have been located all over the State; and along the various water routes manufacturing towns engaged in many forms of industry have been established.

The debt that the manufacturing interests of New York State owe to the glacial accident can never be fully stated. The glacier left the country dotted with lakes; and it left many of the streams turned from their courses down slopes over which they flowed rapidly. For this reason, as in the case of New England, most parts of New York came into the possession of almost unlimited water-power. Without other physiographic advantages this might not have been developed as it has been; but, aided by the facilities for transportation, and by the increasing density of the agricultural population, the region has, as the result of natural causes, become not only a great agricultural district, but also one of the most important manufacturing regions in the country, with large towns and cities and their consequent multitudes of workers demanding products many of which the soil is easily made to furnish. With this development of the home market there came also a *differentiation* in agriculture, until, in addition to grain-raising, there have developed the industries of fruit-raising, dairying, sheep-raising, truck farming and the other great agricultural interests for which New York is noted.

The State has not begun to realize all of its natural resources of water-power, the most impressive example of unused facilities being Niagara Falls, also a product of the glacial accident. This immense cataract, for a long time merely a great fall, to see which people have journeyed from all countries, is now, like its less notable neighbors, which exist by thousands in the State, being made to take a share in the industrial development of New York. This almost inexhaustible water-power is being put to use, though it seems almost desecration to fill the beautiful gorge and line its banks with great tubes and unsightly power-houses, and to transform the border of the cataract into a busy city with its throng of unsympathetic workers. This is, however, an age of progress, in which the needs of mankind take precedence over sentiment, and Niagara is destined not merely to light and furnish the electric power for Buffalo, but also to run countless manufactories in its neighborhood. It promises to become the greatest source of power in the whole world, and to furnish industrially a marvelous illustration of the grandeur of nature's forces as it has in the past filled the traveler with awe.

MINERAL RESOURCES.—The mineral resources of New York have not done much, as compared with many other States, to aid in the industrial development of the region. Aside from iron mined in a few places, certain building-stones, clays, cement and minor products found here and there, and a relatively small amount of petroleum—the northern continuation of the Pennsylvania field—the State has supplied little else of mineral origin excepting salt. This latter product, however, has been of marked importance. While at present it is producing so great an output that it employs many thousands of workers and determines the position of a number of towns and villages, in the past it was even more important, although its output was vastly less extensive. The salt springs at Syracuse, resorted to by the Indians and used by them, became a center of importance in the early days of pioneer travel, and later, when the settlers of the neighborhood needed salt, these springs led to the development of the industry which located one of the large cities of New York. Syracuse has passed the day when it was a great salt-producing city, but the seat of this early industry attained sufficient size to warrant its future development as a result of other industries, one of the most important of which is directly dependent on the salt.

The lack of coal would have been a much greater drawback to New York had it not been for the presence of extensive deposits of this mineral not far away in a neighboring State. Very early this was transported into New York for manufacturing purposes, and across the State for use in more remote regions; and the coal-carrying trade of the early days was one of the important aids to the development of the great water routes of New York, and helped to determine some of the cities, as, for instance, Ithaca.

THE WATERWAYS.—A home and foreign market of the present size could not have been created in New York had there been no natural facilities for the transportation of the products of manufacture. But with facilities for transportation, the agricultural industry has far exceeded the demands of the immediate home market, and the products of the farm, as well as those of the factories, are sent far and wide. While at present man has in some respects risen considerably above the influence of his immediate environment, in the early days of the development of the State the surroundings had an immense influence upon the conditions of life. In those days the time had not yet come when railways could penetrate into the remote, seemingly almost inaccessible, regions; natural pathways were followed, and among these the most potent were the water routes.

The State is traversed by such a series of natural water highways that it has always been possible to travel by water over a large part of its area. Besides the two great lakes, Ontario and Erie—separated, to be sure, by the impassable Niagara Falls—there are Chautauqua Lake, the several Finger Lakes, Oneida Lake, Lake George, Lake Champlain, the St. Lawrence River, the Hudson, the Mohawk, the Susquehanna and the Allegheny, besides innumerable small lakes and rivers. Upon these the Indians traveled by canoe; and the early white pioneers followed the same means of travel. Numerous falls and rapids required "carrys," and "carrys" were often necessary across divides; but, nevertheless, it was possible to penetrate, mainly by water, deeply into the New York wilderness. The importance of this ready access is illustrated with great clearness in the early history of the State; the Dutch settlements along the Hudson, and the pushing of the frontier line up the Mohawk, and out over the plains of north-central New York, and along the lake shores, tell of the important influence of the waterways.

Since railways were not then thought of, as the development of the State continued beyond the primitive stage when canoeing and the use of small boats sufficed, the demand for better means of entrance and exit naturally led to the construction of canals. Owing to the large river valleys, and to the numerous lakes, a few canals opened up to larger boats a great expanse of country. Each of these canals has had an important influence upon the development of the State; but the great scheme for the improvement of the waterways of New York was the building of the long Erie canal. Nature invited this, and the wisdom of some of the early statesmen of New York led to the acceptance of the invitation.

The sinking of the land, or its "drowning," had admitted the ocean tide up the Hudson River beyond Albany. The glacial accident had transformed two streams, one flowing westward, one flowing eastward, into a single east-flowing Mohawk, with a gentle slope from the divide near Rome, with one or two exceptions, all the way down to the Hudson. From Rome westward there stretched a plain greatly leveled by glacial erosion and deposit, and covered so deeply with drift that for a large part of the distance from the Hudson to Lockport, the digging of the canal required merely earth excavation and little rock work. The one great obstacle to the construction of the canal was the escarpment at Lockport, to surmount which considerable ingenuity was required; but, after reaching the crest of the upper plain, the remainder of the route to Buffalo was simple, being over a wonderfully level plain. This opened up communication not only across the the entire State, but to the then unsettled and unknown West. Short side canals connected the Erie canal with Lake Ontario and the Finger Lakes, and these in turn were but a short distance from the Susquehanna.

No one can ever estimate the importance of this canal system in the development of the City of New York and the State as a whole. The *direct* benefits, when it was the only means of transportation of materials, are well understood. The *indirect* influence, in leading to the construction of railways, is, perhaps, not so widely appreciated. There are many who believe that the usefulness of this canal system is of the past; that the present day has outgrown the conditions of canal boating. Doubtless they are correct in so far as canals of the small Erie type are concerned; but no one who has thoughtfully considered the influence of the Erie canal on the past development of New York can have any question as to the future value of an enlarged Erie canal, which shall admit the ships of the lakes and furnish a free passageway across the State. There are always those who question the value of large expenditures; there were such objectors at the time of the proposition to build the Erie Canal itself; and there are now those who question the wisdom of spending large sums in further improvements; but fortunately it is a characteristic of our race that objectors of this kind are always in the minority.

A combination of physiographic causes has conspired to make New York City a great commercial center. The aid of man in the construction of canals, and later of railways, has helped to determine that it shall be the greatest commercial center of the nation, and doubtless, in the not very distant future, of the entire world. It stands at one of the gateways to the interior of the continent, the other two being the St. Lawrence and the Mississippi. The mouth of the latter is too far south, and the most productive part of the country is too distant and too difficult to reach.

The St. Lawrence, with its great city of Montreal, furnishes another natural gateway into the continent, but it is frozen in for months, and, owing to the fact that the international boundary practically prohibits its use as an exit for the products of the northern United States, it leads into a much less productive section than the Hudson gate. The latter, with the aid of canals and the lakes, reaches back into the most productive portion of the American continent. Many railways now lead toward the splendid harbor at the end of the Hudson estuary; and ships that pass down the Hudson and the canal boats that bring loads from the West, are headed toward this great shipping point. It is needed now to make the water connection more perfect.

FIG. 210. Early Buffalo, 1832.

This chapter contains but a general statement of some of the more salient features upon which the development of the State as a whole has depended—a mere hint as to the direction in which it would be easily possible to extend the discussion if we were to commence upon further detail.

It might readily be shown why some parts have become the seats of the dairy industry; others of grain production; others still of vineyards, orchards, etc., either because of features of climate or soil or physiography; and it might also be shown that some portions have remained nearly unsettled and are destined to remain so in the future because of distinctly unfavorable conditions. Moreover, there is scarcely a town whose origin and development have not been profoundly influenced by the surroundings. In some it is water-power and manufacturing; in others agriculture, or the outlet of a canal, or the discovery of iron, salt, oil or other mineral product, etc. How the movements of people, whether for purposes of exploration, war or settlement, have been guided by the physiography offers another inviting field for study. We could also dwell upon the influence of physiography upon those great aids to commercial development, the railways, and study in detail how closely they have been obliged to follow natural routes. One gains an impressive lesson in this connection when he attempts to travel by rail from central New York to western Pennsylvania.

How Buffalo has grown as New York City has developed, because goods bound to or from New York City have often needed to have their mode of transport changed from rail or canal boat to lake boat, or *vice versa!* What a chain of important cities there is along the natural water route and its improved extension, the Erie canal, now followed also by railroads! This is no mere matter of chance; nature provided for it and man merely accepted the conditions, adapted himself to them, and improved upon them where slight improvement promised great reward.

This point of the dependence of industrial development upon the natural conditions is one to which especial attention needs to be called in these days when man so easily overcomes, obstacles, causing railways to ascend to the mountain passes or to plunge directly through the mountains. Now, man is in part the master of his surroundings; but even at present he is not fully free from their influence, and the time was when the environment, more than any other single cause, directed his movements and guided his progress in civilization. We ought not to be allowed to forget this.

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